

## **APPENDIX III**

### **Infiltration Rates Conceptual Cover Design Alternatives**

**Commercial Low-Level Radioactive Waste Disposal Site**

**Richland, Washington**

**Washington State Department of Health  
Office of Radiation Protection**

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**ESTIMATES OF INFILTRATION RATES  
(WATER FLUX)  
THROUGH  
CONCEPTUAL COVER DESIGN ALTERNATIVES**

**For The**

**COMMERCIAL  
LOW-LEVEL RADIOACTIVE WASTE DISPOSAL SITE  
RICHLAND, WASHINGTON**

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**July 22, 2003**

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## 1.0 Introduction

The Washington State Department of Health (DOH) is currently finalizing an Environmental Impact Statement (EIS) for the US Ecology Low-Level Radioactive Waste (LLRW) Facility, located on the U.S. Department of Energy (USDOE) Hanford Reservation near Richland, Washington. The EIS, among other tasks, compares six alternative cover designs. The alternative covers are:

| Cover Design Alternatives   |  |
|-----------------------------|--|
| Cover Design No Action:     | Site Soils Cover   |
| Cover Design Alternative 1: | US Ecology Cover   |
| Cover Design Alternative 2: | Homogenous Cover   |
| Cover Design Alternative 3: | Enhanced Cover   |
|                             | <ul style="list-style-type: none"><li>▪ Asphalt Cover</li><li>▪ GeoSynthetic Cover</li><li>▪ Bentonite Cover</li></ul> |

The cover designs are described in Chapter 3.0 of the EIS.

This report describes modeling done by Michael Fayer of the Pacific Northwest National Laboratory, using the UNSAT-H Version 2.03 computer code (Fayer and Jones 1990), to estimate the flux of water (the infiltration rate) through these different conceptual cover designs. The predicted infiltration rates were then used with other site information to predict, for each cover design, the concentrations of radionuclides in water in a down gradient well. This groundwater pathway analysis was done by Art Rood and is reported in Appendix IV, *Groundwater Concentrations and Drinking Water Doses with Uncertainty for the US Ecology Low-Level Radioactive Waste Disposal Facility, Richland Washington*.

The cover designs are conceptual; that is, they are representative of types of designs that might be used and are not prescriptive. The No Action Cover Design (the Site Soils Cover) is not expected to be used at the site, but it provides a baseline to compare results. All of the designs include vegetation growing on the surface of the cover as a means to limit infiltration through the cover.

## 2.0 The UNSAT-H Computer Code

UNSAT-H Version 2.03 is a one-dimensional model that simulates the dynamic processes of infiltration, drainage, redistribution, surface evaporation, and the uptake of water from soil by plants. The mathematical bases of the model are Richard's equation for water flow, Fick's law for vapor diffusion, and Fourier's law for heat flow. UNSAT-H uses a fully implicit, finite difference method for solving the water and heat flow equations. Plant water uptake is introduced as a sink term at each node and is

calculated as a function of root density, water content, and potential evapotranspiration. The simulated profile can be homogeneous or layered. The boundary conditions can be controlled as either constant (potential or temperature) or flux conditions to reflect actual conditions at a given site. The UNSAT-H computer code is described in Fayer and Jones 1990.

### 3.0 Modifications for DOH EIS Application

Three main modifications were made to Version 2.03 for this application:

- Computer code changed from single to double precision.

This change allows mass balance errors to be reduced, but it increases the size of output files.

- Time stepping algorithm altered.

The ability of the code to continue a problem with the time step size at the minimum value, even though the solution was unacceptable, was eliminated. Instead, the code is stopped if it tries to reduce the time step below the minimum acceptable value. Another change was to eliminate faulty logic in the time stepping algorithm that allowed the code to settle into an infinite loop.

- Ritchie equation modified.

The Ritchie equation is used to partition potential evapotranspiration into potential transpiration and potential evaporation. It was recently discovered that the equation did not fit the original data as well as thought, particularly when leaf area index (LAI) values were low, as they typically are in desert communities. The original equation is:

$$PT = -0.21 + 0.7(LAI)^{0.5}$$

The revised equation is:

$$PT = 0.52(LAI)^{0.5}$$

The revised equation values are listed in Table 1, "Replacement of LAI and Ep/Eo Values."

### 4.0 Input Parameters and Boundary Conditions

The materials used in the cover layers are described below in Section 6.0, "Grain Size Information for Materials Modeled by UNSAT-H." The hydraulic characteristics of these materials used as parameter inputs are described in Table 2, "Hydraulic Parameters for Van Genuchten Equation."

UNSAT-H was run using a 30-year daily rainfall pattern for the Hanford site (1966 until 1995). These data are available from the Hanford meteorological station on the worldwide web, at <http://terrassa.pnl.gov:2080/HMS/>. The precipitation and potential evapotranspiration data from this record were used to create the surface boundary condition. The bottom boundary condition was a steady-state condition found by iterative runs starting with the arbitrary condition of 1 bar (i.e., approximately 1000 cm of suction).

The LAI, which describes the amount of vegetation, and hence transpiration, was varied from 0.0 for the inactive summer and fall months, to 0.1 for the less active winter months (Link 1998), to 0.25 for the active part of the growing season (Link et al 1990).<sup>1</sup> An LAI of 0.25 is a conservative estimate; for comparison a sagebrush-bunchgrass community on the Hanford Reservation had an LAI of 0.40 (Link et al 1990, pg. 169, Fig. 4, for year 1986). This leaf area index range should be verified with experimental vegetation plots at the site or by measuring actual site vegetation, with the soil characteristics matching the characteristics of the soil as modeled.

## **5.0 Modeling Limitations, Simplifications, and Assumptions of Cover System**

Briefly, the limitations, simplifications, and assumptions made when applying the UNSAT-H code are:

- The same vegetative density and growth pattern was assumed for all covers and for all time periods.
- Only one-dimensional, downward flow is modeled.
- Only permeable cover layers are modeled; impermeable layers are not modeled. Therefore, only the upper layers of the proposed and alternative covers were modeled, making these 4 cover designs identical to UNSAT-H.
- The cover layers modeled are modeled as designed, without degradation.

These limitations, simplifications, and assumptions and their implications are described in more detail below.

### **5.1 Vegetative Density and Growth Pattern**

The same range of leaf area index (LAI)<sup>2</sup> was used for all cover designs, regardless of the composition of the top layers. This simplifying assumption was used because the variation expected in vegetative density and growth pattern from cover to cover is minimal compared to: (1) the seasonal variation of plant activity; and (2) the preciseness in knowledge for applying LAI values. Over time, the differences in the

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<sup>1</sup> The less active period extends from day number 320 to day number 90 (day 1 is January 1; day 365 is December 31). The active period extends from day number 90 to day 150. The summer months, days 150 to 320, were assigned an LAI of zero.

<sup>2</sup> The LAI describes the amount of vegetation, and hence transpiration.

plant community between the various cover designs is likely to be minimal because the same processes will affect all covers. For instance, all covers will be affected by deposition of windblown material, natural progression of species, fire, and intrusion by non-native plants such as cheat grass and Russian thistle.<sup>3</sup>

The LAI was varied from zero to 0.25 as described in Section 4 above.

## **5.2 One-Dimensional, Downward Flow, and Impermeable Layers Exclusion Assumptions**

UNSAT-H, being a one-dimensional model, exhibits “ponding” above the impermeable or very low-permeability barriers placed below the capillary break layer (drainage layer) in the proposed cover and in the enhanced design covers. In reality, the “ponded” water is expected to travel horizontally within the capillary break layer and out the side of the cover, as long as the capillary break layer remains unclogged and continuous. However, this drainage to the side cannot be modeled with the one-dimensional UNSAT-H code. Therefore, UNSAT-H was used to model only the upper layers and not the low-permeability or impermeable layers. This simplification has the effect of lumping the three enhanced design covers and the thick silt homogenous cover alternative into one for UNSAT-H infiltration predictions.

The simplification described above also means that no credit is taken for any capability of the lower layers of either the proposed cover or the enhanced design covers to intercept water and drain it out the side of the cover. Instead, these lower layers can be viewed as a “backup system” for these four cover alternatives, a “backup system” that was not included in the groundwater pathway modeling.

Therefore, when the different cover designs are evaluated and ranked, judgment must be used to factor in the importance and abilities of these lower layers of the designs and to rank the three enhanced covers against each other, against the thick silt homogenous cover (which lacks this “backup”), and against the proposed cover (which does have the “backup”). Due to the limitations in modeling, the results of the modeling need to be balanced with other methods and standards of evaluating the various covers.

## **5.3 Covers Modeled as Designed**

UNSAT-H was used to model the infiltration of the various cover alternatives “as designed.” UNSAT-H was not used to simulate such possible conditions as settlement, cracking, degradation of cover materials, clogging of gravel drain layers, burrowing by animals, destruction of vegetation by fire or disease, natural progression of vegetation, intrusion of deep rooted plants such as sage brush and Russian thistle, accumulation of windblown material onsite, or erosion due to wind. In addition to modeling results, the

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<sup>3</sup> By using the same LAI, a baseline is available to compare between the designs of the alternative choices. The US Ecology proposed cover as designed with a gravel mulch top layer is expected to have a lower LAI than the enhanced cover designs, but a change to make the top layer similar to that of the enhanced designs is a minimal change and US Ecology is considering this change.

effects of these types of conditions and their relative importance to each of the alternative covers must be weighed in the overall evaluation and ranking of the alternative covers.

## **6.0 Cover Materials Modeled by UNSAT-H**

The cover materials modeled by UNSAT-H are described below and summarized in Table 3, "Materials and Their Thicknesses as Used in UNSAT-H Cover Recharge Evaluations." The cover materials described are the sources for the hydraulic parameters and not materials that have been acquired for cover construction. Materials actually selected will have to be tested to meet design requirements.

### **6.1 Silt Loam Material**

McGee Ranch silt loam (from the McGee Ranch site, located to the northwest of the Yakima Barricade) is the source for the hydraulic parameters for the silt loam used in the UNSAT-H modeling. Those hydraulic parameters required for UNSAT-H modeling are reported in Fayer et al 1992, an analysis of cover designs for the Hanford site.

### **6.2 Site Sand Material**

Parameters for the site sand material came from hydraulic properties from onsite borehole samples. These borehole samples are described in the US Ecology Closure Plan (US Ecology 1996). Three of these samples (MW5<sup>4</sup>, 50 ft.; MW8, 14.5 ft.; and MW10, 45 ft.) came from depths that might comprise a spoils pile (i.e., site sand). The US Ecology 1996 Closure Plan provides saturated hydraulic conductivity values for these samples. Khaleel and Freeman 1995 provides the remaining UNSAT-H model parameters sampled from onsite wells.

### **6.3 Gravel Correction**

The bulk hydraulic properties of the materials mixed with pea gravel were determined using a method proposed by Bouwer and Rice 1983. The method involves calculating the bulk hydraulic properties of the mix from the hydraulic properties of the matrix (e.g., sand; silt loam) fraction alone and the volume fraction of the gravel.

## **7.0 Summary: UNSAT-H Results and Infiltration Rates Used in Groundwater Modeling**

Table 4, second column, lists the results of infiltration modeling using the UNSAT-H code. For cover designs with capillary breaks over low-permeability barrier layers (all cover alternatives except the thick homogenous cover and the site soils cover), the modeling was done for only those layers above the capillary breaks. The four layers of the thick homogenous cover and three enhanced covers above the capillary break are

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<sup>4</sup> MW = monitoring well



similar and therefore were modeled as the same. Two layers were modeled for the site soils cover.

The UNSAT-H modeling results for all alternative covers are similar to infiltration rates predicted in other ways. The proposed cover (and filled site alternative) infiltration rate of 2.07 mm/year compares well with US Ecology's HELP code modeling, which predicts infiltration rates varying from 1.3 mm/year to 3.0 mm/year (US Ecology 1996). The site soils cover infiltration rate of 19.9 mm/year and the enhanced covers and homogenous cover infiltration rates of essentially zero<sup>5</sup> compares well with field lysimeter tests at Hanford (Fayer and Walters 1995 and Gee et al 1993) and with monitoring results of the Prototype Barrier, an instrumented test cover built in the 200 Area (USDOE 1999). In fact, the silt loam of the Prototype Barrier, over the four years during which the hydrologic performance has been measured, has shown drainage of only a fraction of 0.5 mm/yr.<sup>6</sup>

As described in Section 4 above, UNSAT-H predicted a percolation rate through the three enhanced cover designs and the thick homogenous cover of essentially zero. A zero percolation rate results in a maximum concentration of zero in the groundwater and a dose of zero. Because these "zero" answers do not provide any comparative information and because WDOH cannot be assured that the infiltration rate will stay zero over time, a higher value of 0.5 mm/year was used as the infiltration rate (water flux) in the groundwater flow modeling by Art Rood, described in Appendix IV, "Groundwater Concentrations and Drinking Water Doses with Uncertainty for the US Ecology Low-Level Radioactive Waste Disposal Facility, Richland Washington." This non-zero value is the same as assumed by USDOE in their modeling of the Environmental Restoration Disposal Facility (ERDF) cover (US DOE 1994).

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<sup>5</sup> UNSAT-H calculated the infiltration rate for the enhanced and thick silt homogenous cover designs as "less than 0.001 mm/year," which is essentially zero.

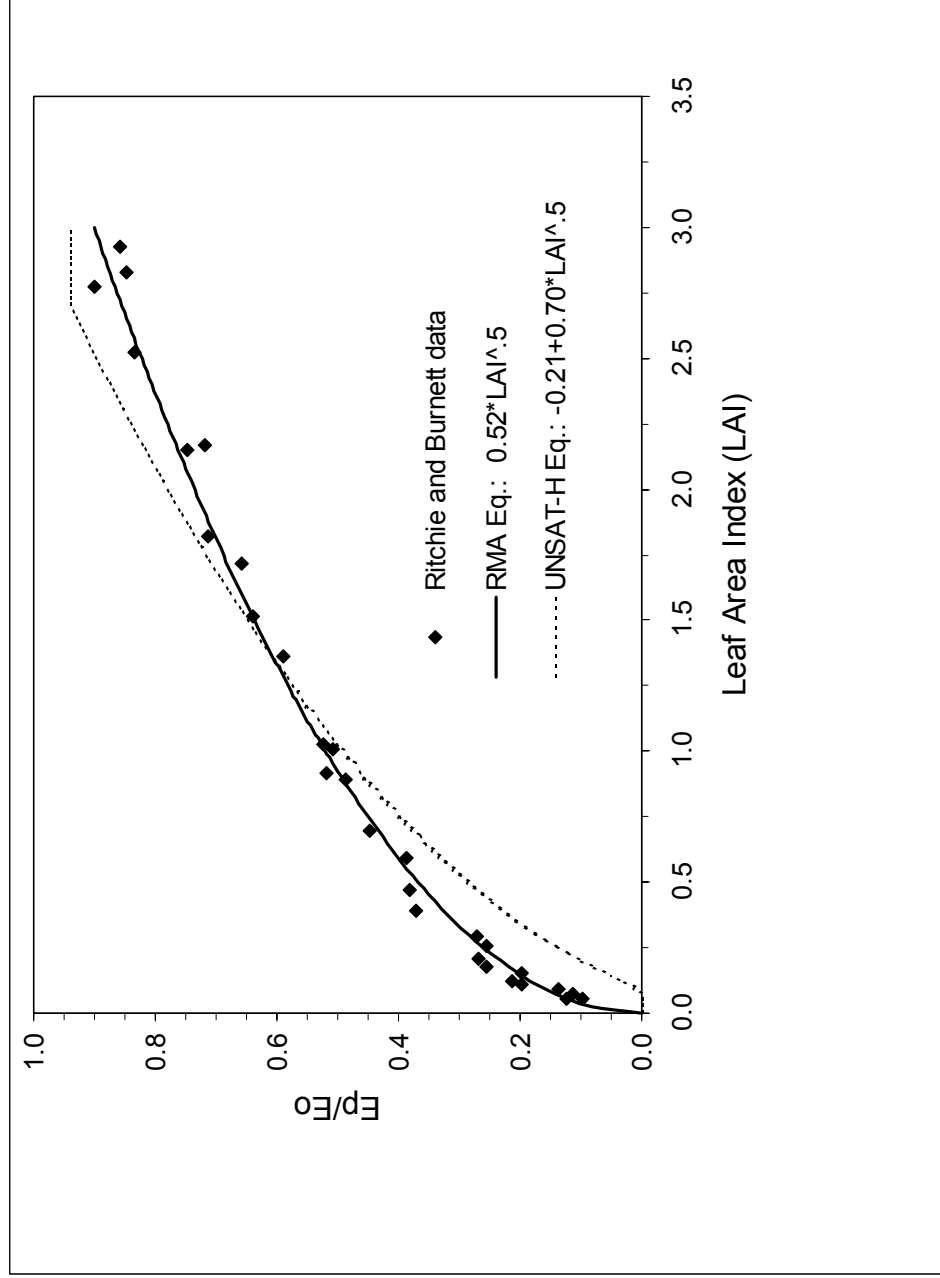
<sup>6</sup> The largest drainage which was measured was 0.07 mm/yr with an above normal level of natural precipitation and 0.02 mm/yr when 3-times the normal precipitation was applied. These amounts can be attributed in part or whole to condensation in the collection system (USDOE 1999, pg 3-24).

## 8.0 Tables

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**Table 1: Replacement of LAI and Ep/Eo Values from Ritchie/UNSAT-H Equation with RMA Equation Values**  
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The graph below, Ep/Eo versus Leaf Area Index, plots Ritchie and Burnett (1971) data against the equation in the UNSAT-H model. It is not a good correlation. An improved correlation is given by the Rocky Mountain Arsenal (RMA) equation also plotted below. The RMA equation is provided by Mark Ankeny of Stan Stevens and Associates, Albuquerque, New Mexico (as yet unpublished).



**KEY**

RMA = Rocky Mountain Arsenal  
 Ep = potential transpiration  
 Eo = sum potential transpiration and potential evaporation  
 LAI = Leaf Area Index  
 Eq = equation

**Table 1: Replacement of LAI and Ep/Eo Values from Ritchie/UNSAT-H Equation with RMA Equation Values**  
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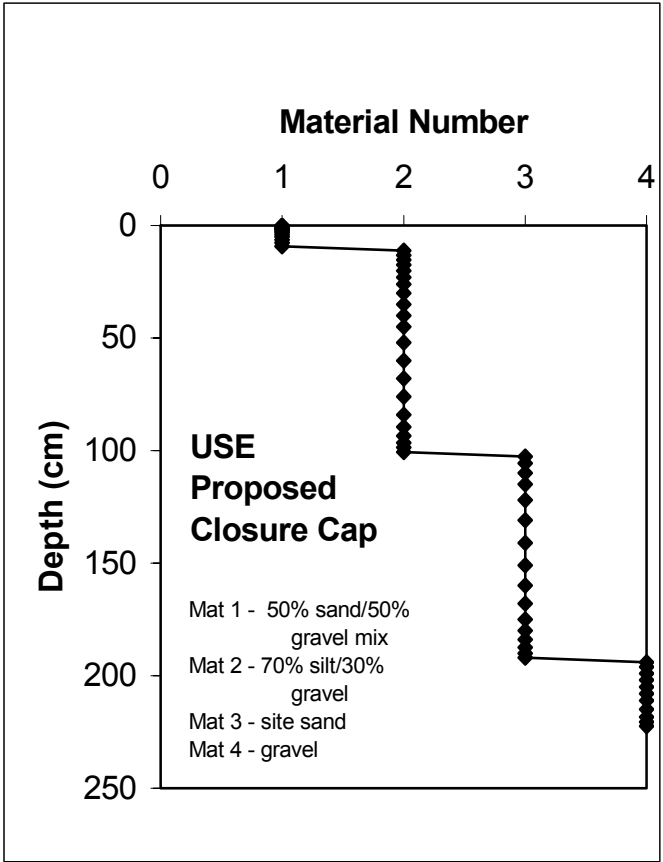
| Digitized Values from Figure 10 of Ritchie and Burnett (1971) |        | Conversion of digitized values in columns 1 and 2 to LAI and Ep/Eo |       | Conversion of Rocky Mountain Arsenal Values to Ritchie Values Ep/Eo |         |             |       |         |             |       |         |             |       |         |             |
|---|--------|--|-------|---|---------|-------------|-------|---------|-------------|-------|---------|-------------|-------|---------|-------------|
| x (cm)  | y (cm) | LAI  | Ep/Eo | LAI   | RMA eq. | Ritchie eq. | LAI   | RMA eq. | Ritchie eq. | LAI   | RMA eq. | Ritchie eq. | LAI   | RMA eq. | Ritchie eq. |
| 0.350   | 2.100  | 0.053  | 0.125 | 0.000   | 0.000   | 0.000       | 1.000 | 0.520   | 0.490       | 2.000 | 0.735   | 0.780       | 2.000 | 0.735   | 0.780       |
| 0.350   | 1.650  | 0.053  | 0.098 | 0.025   | 0.082   | 0.000       | 1.025 | 0.526   | 0.499       | 2.025 | 0.740   | 0.786       | 2.025 | 0.740   | 0.786       |
| 0.600   | 2.300  | 0.090  | 0.137 | 0.050   | 0.116   | 0.000       | 1.050 | 0.533   | 0.507       | 2.050 | 0.745   | 0.792       | 2.050 | 0.745   | 0.792       |
| 0.500   | 1.900  | 0.075  | 0.113 | 0.075   | 0.142   | 0.000       | 1.075 | 0.539   | 0.516       | 2.075 | 0.749   | 0.798       | 2.075 | 0.749   | 0.798       |
| 1.000   | 3.300  | 0.150  | 0.196 | 0.100   | 0.164   | 0.011       | 1.100 | 0.545   | 0.524       | 2.100 | 0.754   | 0.804       | 2.100 | 0.754   | 0.804       |
| 0.800   | 3.600  | 0.120  | 0.214 | 0.125   | 0.184   | 0.037       | 1.125 | 0.552   | 0.532       | 2.125 | 0.758   | 0.810       | 2.125 | 0.758   | 0.810       |
| 0.750   | 3.300  | 0.113  | 0.196 | 0.150   | 0.201   | 0.061       | 1.150 | 0.558   | 0.541       | 2.150 | 0.762   | 0.816       | 2.150 | 0.762   | 0.816       |
| 1.950   | 4.550  | 0.293  | 0.271 | 0.175   | 0.218   | 0.083       | 1.175 | 0.564   | 0.549       | 2.175 | 0.767   | 0.822       | 2.175 | 0.767   | 0.822       |
| 1.700   | 4.300  | 0.255  | 0.256 | 0.200   | 0.233   | 0.103       | 1.200 | 0.570   | 0.557       | 2.200 | 0.771   | 0.828       | 2.200 | 0.771   | 0.828       |
| 1.400   | 4.500  | 0.210  | 0.268 | 0.225   | 0.247   | 0.122       | 1.225 | 0.576   | 0.565       | 2.225 | 0.776   | 0.834       | 2.225 | 0.776   | 0.834       |
| 1.200   | 4.300  | 0.180  | 0.256 | 0.250   | 0.260   | 0.140       | 1.250 | 0.581   | 0.573       | 2.250 | 0.780   | 0.840       | 2.250 | 0.780   | 0.840       |
| 4.650   | 7.500  | 0.698  | 0.446 | 0.275   | 0.273   | 0.157       | 1.275 | 0.587   | 0.580       | 2.275 | 0.784   | 0.846       | 2.275 | 0.784   | 0.846       |
| 3.950   | 6.500  | 0.593  | 0.387 | 0.300   | 0.285   | 0.173       | 1.300 | 0.593   | 0.588       | 2.300 | 0.789   | 0.852       | 2.300 | 0.789   | 0.852       |
| 3.150   | 6.400  | 0.473  | 0.381 | 0.325   | 0.296   | 0.189       | 1.325 | 0.599   | 0.596       | 2.325 | 0.793   | 0.857       | 2.325 | 0.793   | 0.857       |
| 2.600   | 6.250  | 0.390  | 0.372 | 0.350   | 0.308   | 0.204       | 1.350 | 0.604   | 0.603       | 2.350 | 0.797   | 0.863       | 2.350 | 0.797   | 0.863       |
| 5.950   | 8.200  | 0.893  | 0.488 | 0.375   | 0.318   | 0.219       | 1.375 | 0.610   | 0.611       | 2.375 | 0.801   | 0.869       | 2.375 | 0.801   | 0.869       |
| 6.100   | 8.700  | 0.915  | 0.518 | 0.400   | 0.329   | 0.233       | 1.400 | 0.615   | 0.618       | 2.400 | 0.806   | 0.874       | 2.400 | 0.806   | 0.874       |
| 6.700   | 8.550  | 1.005  | 0.509 | 0.425   | 0.339   | 0.246       | 1.425 | 0.621   | 0.626       | 2.425 | 0.810   | 0.880       | 2.425 | 0.810   | 0.880       |
| 6.850   | 8.800  | 1.028  | 0.524 | 0.450   | 0.349   | 0.260       | 1.450 | 0.626   | 0.633       | 2.450 | 0.814   | 0.886       | 2.450 | 0.814   | 0.886       |
| 9.100   | 9.900  | 1.365  | 0.589 | 0.475   | 0.358   | 0.272       | 1.475 | 0.632   | 0.640       | 2.475 | 0.818   | 0.891       | 2.475 | 0.818   | 0.891       |
| 10.100  | 10.750 | 1.515  | 0.640 | 0.500   | 0.368   | 0.285       | 1.500 | 0.637   | 0.647       | 2.500 | 0.822   | 0.897       | 2.500 | 0.822   | 0.897       |
| 11.450  | 11.050 | 1.718  | 0.658 | 0.525   | 0.377   | 0.297       | 1.525 | 0.642   | 0.654       | 2.525 | 0.826   | 0.902       | 2.525 | 0.826   | 0.902       |
| 12.150  | 12.000 | 1.823  | 0.714 | 0.550   | 0.386   | 0.309       | 1.550 | 0.647   | 0.661       | 2.550 | 0.830   | 0.908       | 2.550 | 0.830   | 0.908       |
| 14.350  | 12.550 | 2.153  | 0.747 | 0.575   | 0.394   | 0.321       | 1.575 | 0.653   | 0.668       | 2.575 | 0.834   | 0.913       | 2.575 | 0.834   | 0.913       |
| 14.450  | 12.050 | 2.168  | 0.717 | 0.600   | 0.403   | 0.332       | 1.600 | 0.658   | 0.675       | 2.600 | 0.838   | 0.919       | 2.600 | 0.838   | 0.919       |
| 16.800  | 14.000 | 2.520  | 0.833 | 0.625   | 0.411   | 0.343       | 1.625 | 0.663   | 0.682       | 2.625 | 0.842   | 0.924       | 2.625 | 0.842   | 0.924       |
| 18.500  | 15.100 | 2.775  | 0.899 | 0.650   | 0.419   | 0.354       | 1.650 | 0.668   | 0.689       | 2.650 | 0.846   | 0.930       | 2.650 | 0.846   | 0.930       |
| 18.850  | 14.250 | 2.828  | 0.848 | 0.675   | 0.427   | 0.365       | 1.675 | 0.673   | 0.696       | 2.675 | 0.850   | 0.935       | 2.675 | 0.850   | 0.935       |
| 19.500  | 14.400 | 2.925  | 0.857 | 0.700   | 0.435   | 0.376       | 1.700 | 0.678   | 0.703       | 2.700 | 0.854   | 0.940       | 2.700 | 0.854   | 0.940       |
|   |        |  |       | 0.725   | 0.443   | 0.386       | 1.725 | 0.683   | 0.709       | 2.725 | 0.858   | 0.940       | 2.725 | 0.858   | 0.940       |
|   |        |  |       | 0.750   | 0.450   | 0.396       | 1.750 | 0.688   | 0.716       | 2.750 | 0.862   | 0.940       | 2.750 | 0.862   | 0.940       |
|   |        |  |       | 0.775   | 0.458   | 0.406       | 1.775 | 0.693   | 0.723       | 2.775 | 0.866   | 0.940       | 2.775 | 0.866   | 0.940       |
|   |        |  |       | 0.800   | 0.465   | 0.416       | 1.800 | 0.698   | 0.729       | 2.800 | 0.870   | 0.940       | 2.800 | 0.870   | 0.940       |
|   |        |  |       | 0.825   | 0.472   | 0.426       | 1.825 | 0.702   | 0.736       | 2.825 | 0.874   | 0.940       | 2.825 | 0.874   | 0.940       |
|   |        |  |       | 0.850   | 0.479   | 0.435       | 1.850 | 0.707   | 0.742       | 2.850 | 0.878   | 0.940       | 2.850 | 0.878   | 0.940       |
|   |        |  |       | 0.875   | 0.486   | 0.445       | 1.875 | 0.712   | 0.749       | 2.875 | 0.882   | 0.940       | 2.875 | 0.882   | 0.940       |
|   |        |  |       | 0.900   | 0.493   | 0.454       | 1.900 | 0.717   | 0.755       | 2.900 | 0.886   | 0.940       | 2.900 | 0.886   | 0.940       |
|   |        |  |       | 0.925   | 0.500   | 0.463       | 1.925 | 0.721   | 0.761       | 2.925 | 0.889   | 0.940       | 2.925 | 0.889   | 0.940       |
|   |        |  |       | 0.950   | 0.507   | 0.472       | 1.950 | 0.726   | 0.767       | 2.950 | 0.893   | 0.940       | 2.950 | 0.893   | 0.940       |
|   |        |  |       | 0.975   | 0.513   | 0.481       | 1.975 | 0.731   | 0.774       | 2.975 | 0.897   | 0.940       | 2.975 | 0.897   | 0.940       |
|   |        |  |       |   |         |             |       |         |             | 3.000 | 0.901   | 0.940       | 3.000 | 0.901   | 0.940       |

**Table 2: Hydraulic Parameters for Van Genuchten Equation**  
(Page 1 of 5)

| Cover Type                     | Thickness |                       | Depth Below Surface | ThetaS | ThetaR    | alpha | n          | Hydraulic Conductivity |          |
|--------------------------------|-----------|-----------------------|---------------------|--------|-----------|-------|------------|------------------------|----------|
|                                | in        | cm                    |                     |        |           |       |            | cm/s                   | cm/h     |
| USE Proposed Closure Cap       |           |                       |                     |        |           | 1/cm  |            |                        |          |
| gravel mulch                   | 4         | 10.16                 | 4                   | 0.246  | 0.026     |       | 0.0369     | 3.83E-03               | 13.8     |
| 70% silt/30% gravel            | 36        | 91.44                 | 40                  | 0.408  | 0.000     |       | 0.0178     | 7.85E-04               | 2.83     |
| site sand layer                | 36        | 91.44                 | 76                  | 0.367  | 0.038     |       | 0.0369     | 6.83E-03               | 24.6     |
| gravel (cap break layer)       | 12        | 30.48                 | 88                  | 0.419  | 0.005     |       | 4.93       | 3.50E-01               | 1260     |
| SSSAJ 1990 56:690-700          |           |                       |                     |        |           |       |            |                        |          |
| Baseline Alternative           |           |                       |                     |        |           |       |            |                        |          |
| site sand layer                | 96        | 243.84                | 96                  | 0.367  | 0.038     |       | 0.0369     | 6.83E-03               | 24.6     |
| gravel (cap break layer)       | 6         | 15.24                 | 102                 | 0.419  | 0.005     |       | 4.93       | 3.50E-01               | 1260     |
| SSSAJ 1990 56:690-700          |           |                       |                     |        |           |       |            |                        |          |
| Enhanced Alternative A         |           |                       |                     |        |           |       |            |                        |          |
| 85% silt loam soil/15% gravel  | 30        | 76.20                 | 30                  | 0.452  | 0.0       |       | 0.0178     | 9.39E-04               | 3.38     |
| silt loam soil                 | 30        | 76.20                 | 60                  | 0.496  | 0.0       |       | 0.0178     | 1.12E-03               | 4.03E+00 |
| silt loam corrected for gravel |           |                       |                     |        |           |       |            |                        |          |
| site sand layer                | 63        | 160.02                | 123                 | 0.367  | 0.038     |       | 0.0369     | 6.83E-03               | 24.6     |
| gravel (cap break layer)       | 6         | 15.24                 | 129                 | 0.419  | 0.005     |       | 4.93       | 3.50E-01               | 1260     |
| SSSAJ 1990 56:690-700          |           |                       |                     |        |           |       |            |                        |          |
| Support Calculations           |           |                       |                     |        |           |       |            |                        |          |
|                                | bd        |                       |                     |        |           |       |            |                        |          |
| silt loam                      |           | 1.37                  |                     | 0.496  | 0.00      |       | 0.0178     | 1.12E-03               | 4.03     |
| SSSAJ 1990 56:690-700          |           |                       |                     |        |           |       |            |                        |          |
| site sand                      |           | 1.53                  |                     | 0.367  | 0.0383333 |       | 0.03693333 | 6.83E-03               | 24.6     |
| avg. of 3 samples; no gravel   |           |                       |                     |        |           |       |            |                        |          |
| MW5, sample 50 ft              |           | 1.51                  |                     | 0.331  | 0.037     |       | 0.0395     | 3.53E-02               | 127      |
| USE Closure Plan               |           |                       |                     |        |           |       |            |                        |          |
| MW8, sample 14.5 ft            |           | 1.51                  |                     | 0.431  | 0.040     |       | 0.0425     | 1.70E-03               | 6.12     |
| USE Closure Plan               |           |                       |                     |        |           |       |            |                        |          |
| MW10, sample 45 ft             |           | 1.57                  |                     | 0.339  | 0.038     |       | 0.0288     | 5.31E-03               | 19.1     |
| USE Closure Plan               |           |                       |                     |        |           |       |            |                        |          |
| silt loam/30%/gravel mix       |           |                       |                     |        |           |       |            |                        |          |
|                                |           |                       |                     |        |           |       |            |                        |          |
| silt loam/15%/gravel mix       |           |                       |                     |        |           |       |            |                        |          |
| mix: assumed bulk density      | 1.6       | assumed               |                     |        |           |       |            | 1.6                    | assumed  |
| silt loam part. den.           | 2.72      | assumed               |                     |        |           |       |            | 2.72                   | assumed  |
| gravel part. den.              | 2.72      | assumed               |                     |        |           |       |            | 2.72                   | assumed  |
| gravel % by wt.                | 30        |                       |                     |        |           |       | 15         |                        |          |
| Vol frac of gravel (Vr)        | 0.176471  |                       |                     |        |           |       | 0.0882353  |                        |          |
| ThetaS (TS)                    | 0.496     |                       |                     |        |           |       | 0.496      |                        |          |
| ThetaSbulk (TSb)               | 0.408471  |                       |                     |        |           |       | 0.452      |                        |          |
| k reduction factor             | 0.701671  | (1-Vr)*(1-TS)/(1-TSb) |                     |        |           |       | 0.839      | (1-Vr)*(1-TS)/(1-TSb)  |          |
| site sand/gravel mix           |           |                       |                     |        |           |       |            |                        |          |
| mix: assumed bulk density      | 1.8       | assumed               |                     |        |           |       |            | 1.8                    | assumed  |
| sand part. den.                | 2.65      | assumed               |                     |        |           |       |            | 2.65                   | assumed  |
| gravel part. den.              | 2.72      | assumed               |                     |        |           |       |            | 2.72                   | assumed  |
| gravel % by wt.                | 50        |                       |                     |        |           |       |            |                        |          |
| Vol frac of gravel (Vr)        | 0.330882  |                       |                     |        |           |       |            |                        |          |
| ThetaS (TS)                    | 0.367     |                       |                     |        |           |       |            |                        |          |
| ThetaSbulk (TSb)               | 0.245566  |                       |                     |        |           |       |            |                        |          |
| k reduction factor             | 0.561416  | (1-Vr)*(1-TS)/(1-TSb) |                     |        |           |       |            |                        |          |

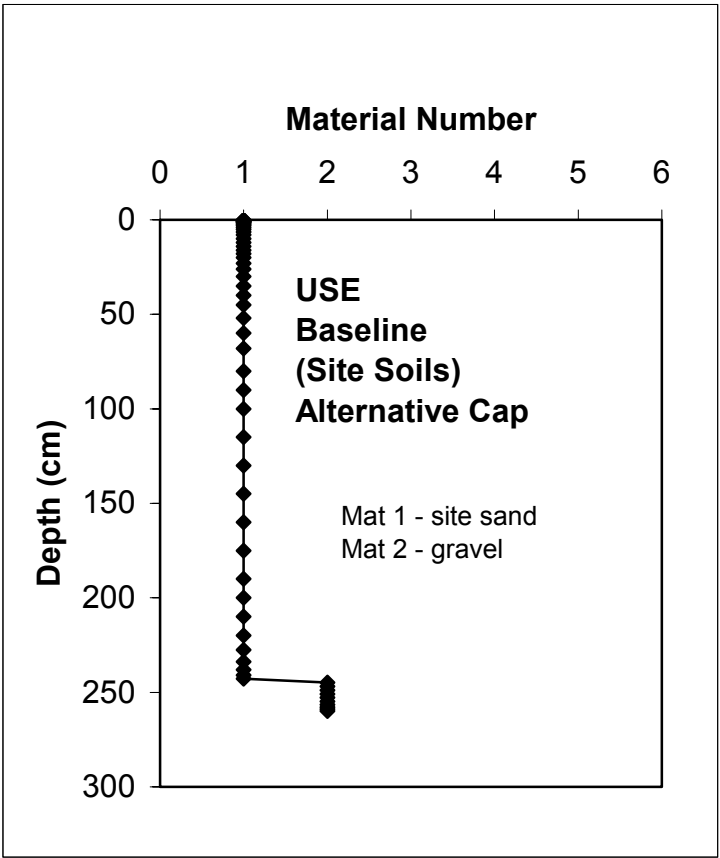
**Table 2: Hydraulic Parameters for Van Genuchten Equation**  
(Page 2 of 5)

| Node No. | Material No. | Node Z, cm | ZZ, cm | Change in ZZ < 50%? |
|----------|--------------|------------|--------|---------------------|
| 1        | 1            | 0          |        |                     |
| 2        | 1            | 0.2        | 0.2    |                     |
| 3        | 1            | 0.4        | 0.2    | ok                  |
| 4        | 1            | 0.6        | 0.2    | ok                  |
| 5        | 1            | 0.8        | 0.2    | ok                  |
| 6        | 1            | 1          | 0.2    | ok                  |
| 7        | 1            | 1.3        | 0.3    | ok                  |
| 8        | 1            | 1.7        | 0.4    | ok                  |
| 9        | 1            | 2.3        | 0.6    | ok                  |
| 10       | 1            | 3          | 0.7    | ok                  |
| 11       | 1            | 4          | 1      | ok                  |
| 12       | 1            | 5          | 1      | ok                  |
| 13       | 1            | 6.3        | 1.3    | ok                  |
| 14       | 1            | 7.6        | 1.3    | ok                  |
| 15       | 1            | 9.16       | 1.56   | ok                  |
| 16       | 2            | 11.16      | 2      | ok                  |
| 17       | 2            | 13.16      | 2      | ok                  |
| 18       | 2            | 15.25      | 2.09   | ok                  |
| 19       | 2            | 17.5       | 2.25   | ok                  |
| 20       | 2            | 20         | 2.5    | ok                  |
| 21       | 2            | 23         | 3      | ok                  |
| 22       | 2            | 26         | 3      | ok                  |
| 23       | 2            | 30         | 4      | ok                  |
| 24       | 2            | 35         | 5      | ok                  |
| 25       | 2            | 40         | 5      | ok                  |
| 26       | 2            | 45         | 5      | ok                  |
| 27       | 2            | 52         | 7      | ok                  |
| 28       | 2            | 60         | 8      | ok                  |
| 29       | 2            | 68         | 8      | ok                  |
| 30       | 2            | 76         | 8      | ok                  |
| 31       | 2            | 84         | 8      | ok                  |
| 32       | 2            | 89.5       | 5.5    | ok                  |
| 33       | 2            | 93.5       | 4      | ok                  |
| 34       | 2            | 96.5       | 3      | ok                  |
| 35       | 2            | 98.6       | 2.1    | ok                  |
| 36       | 2            | 100.6      | 2      | ok                  |
| 37       | 3            | 102.6      | 2      | ok                  |
| 38       | 3            | 105.6      | 3      | ok                  |
| 39       | 3            | 110        | 4.4    | ok                  |
| 40       | 3            | 115        | 5      | ok                  |
| 41       | 3            | 122        | 7      | ok                  |
| 42       | 3            | 131        | 9      | ok                  |
| 43       | 3            | 141        | 10     | ok                  |
| 44       | 3            | 151        | 10     | ok                  |
| 45       | 3            | 160        | 9      | ok                  |
| 46       | 3            | 168        | 8      | ok                  |
| 47       | 3            | 175        | 7      | ok                  |
| 48       | 3            | 180        | 5      | ok                  |
| 49       | 3            | 184        | 4      | ok                  |
| 50       | 3            | 187.5      | 3.5    | ok                  |
| 51       | 3            | 190.04     | 2.54   | ok                  |
| 52       | 3            | 192.04     | 2      | ok                  |
| 53       | 4            | 194.04     | 2      | ok                  |
| 54       | 4            | 196.04     | 2      | ok                  |
| 55       | 4            | 199        | 2.96   | ok                  |
| 56       | 4            | 202        | 3      | ok                  |
| 57       | 4            | 205        | 3      | ok                  |
| 58       | 4            | 208        | 3      | ok                  |
| 59       | 4            | 211        | 3      | ok                  |
| 60       | 4            | 215        | 4      | ok                  |
| 61       | 4            | 218.3      | 3.3    | ok                  |
| 62       | 4            | 220.52     | 2.22   | ok                  |
| 63       | 4            | 222.52     | 2      | ok                  |
| 64       | 4            | 223.52     | 1      | -100                |



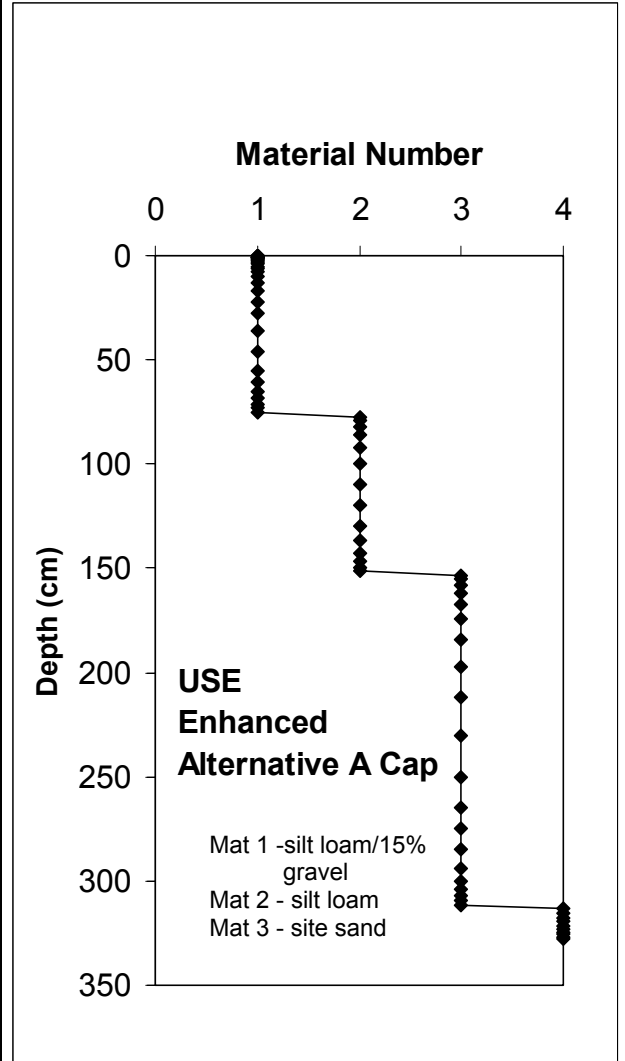
**Table 2: Hydraulic Parameters for Van Genuchten Equation**  
(Page 3 of 5)

| Node No. | Material No. | Node Z, cm | ZZ, cm | Change in ZZ < 50%? |
|----------|--------------|------------|--------|---------------------|
| 1        | 1            | 0          |        |                     |
| 2        | 1            | 0.2        | 0.2    |                     |
| 3        | 1            | 0.4        | 0.2    | ok                  |
| 4        | 1            | 0.6        | 0.2    | ok                  |
| 5        | 1            | 0.8        | 0.2    | ok                  |
| 6        | 1            | 1          | 0.2    | ok                  |
| 7        | 1            | 1.3        | 0.3    | ok                  |
| 8        | 1            | 1.7        | 0.4    | ok                  |
| 9        | 1            | 2.3        | 0.6    | ok                  |
| 10       | 1            | 3          | 0.7    | ok                  |
| 11       | 1            | 4          | 1      | ok                  |
| 12       | 1            | 5          | 1      | ok                  |
| 13       | 1            | 6.5        | 1.5    | ok                  |
| 14       | 1            | 8          | 1.5    | ok                  |
| 15       | 1            | 10         | 2      | ok                  |
| 16       | 1            | 12         | 2      | ok                  |
| 17       | 1            | 14         | 2      | ok                  |
| 18       | 1            | 16         | 2      | ok                  |
| 19       | 1            | 18         | 2      | ok                  |
| 20       | 1            | 20         | 2      | ok                  |
| 21       | 1            | 23         | 3      | ok                  |
| 22       | 1            | 26         | 3      | ok                  |
| 23       | 1            | 30         | 4      | ok                  |
| 24       | 1            | 35         | 5      | ok                  |
| 25       | 1            | 40         | 5      | ok                  |
| 26       | 1            | 45         | 5      | ok                  |
| 27       | 1            | 52         | 7      | ok                  |
| 28       | 1            | 60         | 8      | ok                  |
| 29       | 1            | 68         | 8      | ok                  |
| 30       | 1            | 80         | 12     | ok                  |
| 31       | 1            | 90         | 10     | ok                  |
| 32       | 1            | 100        | 10     | ok                  |
| 33       | 1            | 115        | 15     | ok                  |
| 34       | 1            | 130        | 15     | ok                  |
| 35       | 1            | 145        | 15     | ok                  |
| 36       | 1            | 160        | 15     | ok                  |
| 37       | 1            | 175        | 15     | ok                  |
| 38       | 1            | 190        | 15     | ok                  |
| 39       | 1            | 200        | 10     | ok                  |
| 40       | 1            | 210        | 10     | ok                  |
| 41       | 1            | 220        | 10     | ok                  |
| 42       | 1            | 227.5      | 7.5    | ok                  |
| 43       | 1            | 233.75     | 6.25   | ok                  |
| 44       | 1            | 238.0      | 4.25   | ok                  |
| 45       | 1            | 240.84     | 2.84   | ok                  |
| 46       | 1            | 242.84     | 2      | ok                  |
| 47       | 2            | 244.84     | 2      | ok                  |
| 48       | 2            | 246.84     | 2      | ok                  |
| 49       | 2            | 248.84     | 2      | ok                  |
| 50       | 2            | 250.84     | 2      | ok                  |
| 51       | 2            | 252.84     | 2      | ok                  |
| 52       | 2            | 254.84     | 2      | ok                  |
| 53       | 2            | 256.5      | 1.66   | ok                  |
| 54       | 2            | 257.8      | 1.3    | ok                  |
| 55       | 2            | 258.8      | 1      | ok                  |
| 56       | 2            | 259.8      | 1      | ok                  |



**Table 2: Hydraulic Parameters for Van Genuchten Equation**  
(Page 4 of 5)

| Node No. | Material No. | Node Z, cm | ZZ, cm | Change in ZZ < 50%? |
|----------|--------------|------------|--------|---------------------|
| 1        | 1            | 0          |        |                     |
| 2        | 1            | 0.2        | 0.2    |                     |
| 3        | 1            | 0.4        | 0.2    | ok                  |
| 4        | 1            | 0.6        | 0.2    | ok                  |
| 5        | 1            | 0.8        | 0.2    | ok                  |
| 6        | 1            | 1          | 0.2    | ok                  |
| 7        | 1            | 1.3        | 0.3    | ok                  |
| 8        | 1            | 1.7        | 0.4    | ok                  |
| 9        | 1            | 2.3        | 0.6    | ok                  |
| 10       | 1            | 3          | 0.7    | ok                  |
| 11       | 1            | 4          | 1      | ok                  |
| 12       | 1            | 5          | 1      | ok                  |
| 13       | 1            | 6.5        | 1.5    | ok                  |
| 14       | 1            | 8          | 1.5    | ok                  |
| 15       | 1            | 10         | 2      | ok                  |
| 16       | 1            | 13         | 3      | ok                  |
| 17       | 1            | 17         | 4      | ok                  |
| 18       | 1            | 22         | 5      | ok                  |
| 19       | 1            | 28         | 6      | ok                  |
| 20       | 1            | 36         | 8      | ok                  |
| 21       | 1            | 46         | 10     | ok                  |
| 22       | 1            | 55         | 9      | ok                  |
| 23       | 1            | 61         | 6      | ok                  |
| 24       | 1            | 65         | 4      | ok                  |
| 25       | 1            | 68         | 3      | ok                  |
| 26       | 1            | 71         | 3      | ok                  |
| 27       | 1            | 73.2       | 2.2    | ok                  |
| 28       | 1            | 75.2       | 2      | ok                  |
| 29       | 2            | 77.2       | 2      | ok                  |
| 30       | 2            | 79.2       | 2      | ok                  |
| 31       | 2            | 82         | 2.8    | ok                  |
| 32       | 2            | 86         | 4      | ok                  |
| 33       | 2            | 92         | 6      | ok                  |
| 34       | 2            | 100        | 8      | ok                  |
| 35       | 2            | 110        | 10     | ok                  |
| 36       | 2            | 120        | 10     | ok                  |
| 37       | 2            | 130        | 10     | ok                  |
| 38       | 2            | 137        | 7      | ok                  |
| 39       | 2            | 142.5      | 5.5    | ok                  |
| 40       | 2            | 146.5      | 4      | ok                  |
| 41       | 2            | 149.4      | 2.9    | ok                  |
| 42       | 2            | 151.4      | 2      | ok                  |





**Table 2: Hydraulic Parameters for Van Genuchten Equation**  
(Page 5 of 5 – table continued from previous page)

| Node No. | Material No. | Node Z, cm | ZZ, cm | Change in ZZ < 50%? |
|----------|--------------|------------|--------|---------------------|
| 43       | 3            | 153.4      | 2      | ok                  |
| 44       | 3            | 154        | 2      | ok                  |
| 45       | 3            | 158.2      | 2.8    | ok                  |
| 46       | 3            | 162        | 3.8    | ok                  |
| 47       | 3            | 167        | 5      | ok                  |
| 48       | 3            | 174        | 7      | ok                  |
| 49       | 3            | 184.0      | 10     | ok                  |
| 50       | 3            | 197        | 13     | ok                  |
| 51       | 3            | 212        | 15     | ok                  |
| 52       | 3            | 230        | 18     | ok                  |
| 53       | 3            | 250        | 20     | ok                  |
| 54       | 3            | 265        | 15     | ok                  |
| 55       | 3            | 275        | 10     | ok                  |
| 56       | 3            | 285        | 10     | ok                  |
| 57       | 3            | 294        | 9      | ok                  |
| 58       | 3            | 300        | 6      | ok                  |
| 59       | 3            | 304        | 4      | ok                  |
| 60       | 3            | 307        | 3      | ok                  |
| 61       | 3            | 309.42     | 2.42   | ok                  |
| 62       | 3            | 311.42     | 2      | ok                  |
| 63       | 4            | 313.42     | 2      | ok                  |
| 64       | 4            | 315.42     | 2      | ok                  |
| 65       | 4            | 317.42     | 2      | ok                  |
| 66       | 4            | 319.42     | 2      | ok                  |
| 67       | 4            | 321.42     | 2      | ok                  |
| 68       | 4            | 323.2      | 1.78   | ok                  |
| 69       | 4            | 324.66     | 1.46   | ok                  |
| 70       | 4            | 325.66     | 1      | ok                  |
| 71       | 4            | 326.66     | 1      | ok                  |
| 72       | 4            | 327.66     | 1      | ok                  |

**Table 3: Materials and Their Thicknesses as Used in Unsat-H Cover Recharge Evaluations**

| Materials (from top of cover down)  | Thicknesses (in.) of Cover Layers |            |                        | Data Sources  |
|-------------------------------------|-----------------------------------|------------|------------------------|---|
|                                     | US Ecology Proposed Cover         | Site Soils | Enhanced Cover Designs |   |
| 50% site sand mixed with 50% gravel | 4                                 |            |                        | Same as for site sand; with correction for gravel content                                       |
| 85% silt loam mixed with 15% gravel |                                   |            | 30                     | Same as for site sand; with correction for gravel content                                       |
| 70% silt loam mixed with 30% gravel | 36                                |            |                        | Same as for site sand; with correction for gravel content                                       |
| Silt loam                           |                                   |            | 30                     | Fayer et al 1992  |
| Site sand                           | 36                                | 96         | 63                     | US Ecology Site Closure Plan, 1996; Khaleel and Freeman 1995 (US Ecology site well information) |
| Gravel                              | 12                                | 6          | 6                      | Fayer et al 1992  |
| Number of layers                    | 4                                 | 2          | 4                      | Number of layers  |

**Table 4: Comparison of UNSAT-H Code Predicted Infiltration Rates with Infiltration Rates Used in Groundwater Modeling**

| Cover Alternative Modeled                  | UNSAT-H Predicted Infiltration Rates, Top Layers | Infiltration Rates <sup>(1)</sup> Used in Groundwater Modeling | Number of Layers Modeled |
|--|--|--|--------------------------|
| Site Soils Cover                           | 19.9 mm/year                                     | 20 mm/year   | 2                        |
| US Ecology Cover                           | 2.07 mm/year                                     | 2 mm/year  | 4                        |
| Thick Silt Homogenous Cover <sup>(2)</sup> | Less than .001 mm/year <sup>(3)</sup>            | 0.5 mm/year  | 4                        |
| Enhanced Asphalt Cover                     | Less than .001 mm/year <sup>(3)</sup>            | 0.5 mm/year  | 4                        |
| Enhanced GeoSynthetic Cover                | Less than .001 mm/year <sup>(3)</sup>            | 0.5 mm/year  | 4                        |
| Enhanced Bentonite Cover                   | Less than .001 mm/year <sup>(3)</sup>            | 0.5 mm/year  | 4                        |

- (1) "Infiltration rate" termed "water flux" in groundwater modeling.
- (2) Same predicted value as the enhanced cover designs, but homogenous cover would probably over time have a higher infiltration rate than the enhanced cover designs because the homogenous cover does not have redundant layering.
- (3) UNSAT-H modeling results are reported as "less than 0.001 mm/year," which is essentially zero. In order to be conservative, 0.5 mm/year (0.0005 m/year) is the value actually used in GWSCREEN computer code modeling. There is no reason to run GWSCREEN with an infiltration rate of zero; all doses would be zero.

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