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# Justification for Use of the HELP Model to Estimate Infiltration Rates for the E-Area Low-Level Waste Facility Performance Assessment

J. A. Dyer

December 2019

SRNL-STI-2019-00362, Revision 0



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Prepared for the U.S. Department of Energy under contract number DE-AC09-08SR22470.

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

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### **EXECUTIVE SUMMARY**

This report supplements the infiltration data package report prepared by Dyer (2019) for the upcoming E-Area Low-Level Waste Facility (LLWF) Performance Assessment (PA) and provides further justification for the use of the Hydrologic Evaluation of Landfill Performance (HELP) model for E-Area PA infiltration calculations. Three items are addressed:

- 1. A comparison of HELP model results to field- and modeling-based water balance, soil infiltration, and groundwater recharge studies that have been conducted at or near the Savannah River Site (SRS) over several decades.
- 2. An evaluation of the hydrologic model and design and performance recommendations for the planned Saltstone Disposal Facility closure cap at SRS.
- 3. A side-by-side comparison of the HYDRUS-1D and HELP models to assess their capabilities to efficiently perform the wide range of intact and subsidence infiltration model simulations across multiple disposal unit types as required for the E-Area LLWF PA.

Net infiltration/recharge rates for ten studies conducted at or near SRS over several decades range from 9.1 to 16 inches/year with a median of 14.5 inches/year, which is approximately one-third of the median annual-average precipitation rate of 47.79 inches for the ten studies. The infiltration/recharge rates compare favorably with the results of HELP model simulations for the operational soil cover scenario: 49.14 inches annual-average precipitation, 0.029 inches/year surface runoff, 33.27 inches/year evapotranspiration, and 15.78 inches/year net infiltration.<sup>1</sup>

For the Saltstone Disposal Facility PA, Benson (2018) coupled WinUNSAT-H to simulate percolation in earthen layers above the lateral drainage layer with the Giroud equations (Giroud and Houlihan, 1995; Giroud, 1997; Giroud et al., 2000; Giroud et al., 2004) to model lateral drainage flow and composite barrier leakage (i.e., geomembrane/geosynthetic clay liner/finely textured foundation layer). Because the composite barrier in a multilayer cap design provides the predominant resistance to flow, a comparison of percolation rates through the coupled lateral drainage and composite barrier layers only was made for the E-Area Slit-and-Engineered-Trench intact case using the Giroud equations and the HELP model. Agreement between the two models was satisfactory through the first 300 years when the number of defects (holes) in the geomembrane is small. Beyond 300 years, the difference in predicted infiltration rates by the two models increases significantly with the Giroud equations calculating a much larger percolation rate through the geomembrane defects.

With one exception (single upper HDPE layer during institutional control), side-by-side comparisons of HELP and HYDRUS-1D were limited to earthen layers only for several reasons. First, HYDRUS-1D is fundamentally an agricultural modeling tool for simulating water and solute transport in variably-saturated porous media composed of non-uniform soils. There is no mechanism, for example, to easily model a composite barrier layer with defects (holes). Second, HYDRUS-1D includes a lower boundary condition that simulates horizontal drainage for a tile drainage system with an impermeable layer at the base. The tile drainage model is not adequately representative of a multilayer cover system with a

<sup>&</sup>lt;sup>1</sup> A change in soil water storage equal to +0.071 inches/year is also reported by the HELP model to satisfy the water mass balance (annual avg. precipitation = evapotranspiration +  $\Delta$  water storage + surface runoff + net infiltration).

separate lateral drainage layer above and free drainage at the base below. Third, HYDRUS-1D utilizes the Richards equation to model variably-saturated flow, which makes model convergence challenging for layered systems comprised of materials with widely varying porosities and saturated hydraulic conductivities (e.g., a low-permeability composite barrier sandwiched between permeable earthen layers). Conversely, convergence is rarely an issue for HELP, which is a mass balance model.

In summary, the HELP model was designed specifically for simulating infiltration through multilayer closure-cap systems, and it remains the best option for modeling such systems in wet climates where a unit hydraulic gradient is a reasonable assumption. As a mass-balance model, HELP is well suited for PA evaluations where flexibility in the model framework and ease of model convergence are important. Existing hydrologic models that use the Richards equation for variably-saturated flow, on the other hand, are not designed specifically for multilayer landfill cover systems, are more difficult to converge, and often must be coupled with a second model for drainage and composite barrier layers. Although computational codes that solve the Richards equation are more sophisticated than HELP, they can be challenging to use with a high level of accuracy when percolation rates are very low and extend over long periods (Whiteside et al., 2009). In fact, mass-balance errors associated with the numerical model simulations are of the same order of magnitude as the percolation rates themselves. The WinUNSAT-H and HYDRUS programs are better suited instead for simulating evapotranspiration cover systems typically found in arid and semi-arid climates. Evapotranspiration cover systems rely on the ability of a soil laver to store precipitation until it is naturally evaporated or transpired by a vegetative cover (U.S. EPA, 2011). This contrasts with more conventional cover systems that are engineered with a composite barrier layer of low hydraulic conductivity.

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## LIST OF ABBREVIATIONS

GCL	Geosynthetic clay liner
GUI	Graphical User Interface
HDPE	High-density polyethylene
HELP	Hydrologic Evaluation of Landfill Performance
K <sub>sat</sub>	Saturated hydraulic conductivity
LFRG	Low-Level Waste Disposal Facility Federal Review Group
LLWF	Low-Level Waste Facility
ORWBG	Old Radioactive Waste Burial Ground
PA	Performance Assessment
SDF	Saltstone Disposal Facility
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
USGS	United States Geological Survey

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#### **1.0 Introduction**

Whiteside et al. (2009) conducted an in-depth literature review and performed basic infiltration model simulations to evaluate the Hydrologic Evaluation of Landfill Performance (HELP) model against five alternative computational codes utilizing the Richards equation for variably-saturated flow. Of the five alternatives considered (LEACHM, UNSAT-H, SVFlux, HYDRUS-2D3D, and VADOSE/W), only HYDRUS-2D3D and VADOSE/W were selected for further evaluation, which consisted of a side-by-side comparison versus HELP of calculated infiltration rates through a one-layer soil column with two percent slope. At the time, Whiteside et al. (2009) recommended HYDRUS-2D3D over VADOSE/W for the following reasons:

- The HYDRUS software suite was more widely known and used than VADOSE/W. In addition, the one-dimensional version of HYDRUS, HYDRUS-1D, was (and still is) available for download in the public domain. Both may be important considerations for reviewers and other stakeholders.
- The licensing cost was much lower for HYDRUS-2D3D than VADOSE/W.
- While a two-dimensional code is adequate for most cover systems, the three-dimensional modeling capability of HYDRUS-2D3D would potentially allow for analysis of discrete holes in high-density polyethylene (HDPE) and GCL liners, if needed.
- HYDRUS-2D3D simulates multiphase flow and transport, while VADOSE/W models the liquid-phase only.
- The graphical user interface (GUI) for HYDRUS-2D3D was more robust during the limited testing. The VADOSE/W GUI regularly experienced a fatal error that prevented completion of numerical simulations.

On the other hand, the authors were inconclusive about using HYDRUS-2D3D in place of the HELP model pending more rigorous simulations of a multilayer closure cap design.

This report does not repeat the earlier study by Whiteside et al. (2009), but instead focuses on the following secondary issue raised in the Department of Energy's Low-Level Waste Disposal Facility Federal Review Group (LFRG) review team report (LFRG, 2008) for the 2008 E-Area Low-Level Waste Facility (LLWF) Performance Assessment (PA) as summarized by McDowell-Boyer et al. (2011):

"7.2.3.1: The HELP code that provided the basis of the cap infiltration analyses is well tested, generally accepted, and has been benchmarked against a broad range of codes that perform similar calculations. However, there is no discussion of the HELP modeling results with respect to the results of other analyses. Input parameters for HELP were difficult to find and were found in multiple documents cited in Phifer (2006).

Proposed Resolution: A discussion of the HELP modeling results with respect to other modeling results for other analyses using available site data and information should be added. These data should be compiled into a single data package in the PA."

The infiltration data package prepared by Dyer (2019) for the upcoming E-Area LLWF PA satisfies, to a large extent, the LFRG's proposed resolution to the secondary issue above. This report supplements the infiltration data package, providing more "discussion of the HELP modeling results with respect to the results of other analyses."

#### 2.0 Net Soil Infiltration Rates at the Savannah River Site

Numerous field- and modeling-based water balance, soil infiltration, and groundwater recharge studies have been conducted at or near the Savannah River Site (SRS) over several decades by organizations including the Savannah River National Laboratory (SRNL), United States Geological Survey (USGS), State University of New York at Brockport, Pennsylvania State University, University of Arizona, and Desert Research Institute (WSRC, 2008). The studies have ranged in scale from 55-gallon drum lysimeters to entire watersheds.

The USGS performed two studies at the Barnwell Low-Level Radioactive Waste Disposal Facility, which is located immediately east of SRS. Cahill (1982) investigated geologic and hydrologic conditions near the Barnwell site and measured migration of leachates from the buried waste into surrounding unconsolidated sediments. Seven years later, Dennehy and McMahon (1989) assessed the principal factors affecting the movement of water within and adjacent to trenches excavated in the unsaturated zone.

Mean-annual groundwater discharge to streams (i.e., baseflow) is thought to approximate the long-term average recharge to local, intermediate, and regional components of the groundwater-flow system (Clarke and West, 1998). Stricker (1983) analyzed baseflow stream data from USGS gaging stations located within the Cretaceous and Tertiary clastic outcrop area of South Carolina, Georgia, Alabama, and Mississippi to estimate groundwater recharge to the southeastern sand aquifer, which includes Upper Three Runs near New Ellenton, SC. Meanwhile, Clarke and West (1998) used MODFLOW to simulate groundwater flow and stream–aquifer relations for seven aquifers in Coastal Plain sediments near SRS, including three gaging stations in the Upper Three Runs basin (water years 1967-1993 and 1975-1993).

Hubbard and Emslie (1984) from the State University of New York at Brockport collaborated with the Savannah River Laboratory (which was designated a national laboratory in 2004) to develop a water budget for the Savannah River Plant Old Radioactive Waste Burial Ground (ORWBG). The ORWBG water balance was updated in 1986 using information from the Defense Waste Lysimeter study (Hubbard, 1986). Finally, the State University of New York at Brockport, in collaboration with the University of Arizona, used the CREAMS model and site-specific weather data for 1961 through 1986 to generate annual water balances for the ORWBG (Hubbard and Englehardt, 1987).

Parizek and Root (1986) from the Pennsylvania State University completed a hydrologic water budget for the McQueen Branch watershed in the central portion of SRS as part of the development of a groundwater model.

Young and Pohlmann (2001) at the Desert Research Institute conducted both deterministic and probabilistic (100 Monte Carlo realizations) simulations utilizing the HYDRUS 2-D finite-difference model to estimate infiltration rates within E-Area at SRS. The model was refined in 2003 to incorporate additional site-specific data (Young and Pohlmann, 2003).

Table 2-1 summarizes relevant annual-average water balance, infiltration, and groundwater recharge estimates from the ten studies introduced above. Net infiltration/recharge rates range from 9.1 to 16 inches/year with a median of 14.5 inches/year, which is approximately one-third of the median annual-average precipitation rate of 47.79 inches for the ten studies. The rates in Table 2-1 compare favorably with the results of HELP model simulations for the operational soil cover scenario: 49.14 inches annual-average precipitation, 0.029 inches/year surface runoff, 33.27 inches/year evapotranspiration, and 15.78 inches/year net infiltration.<sup>2</sup>

Sourco	Annual-Average Rate (inches/year) <sup>a</sup>					
Source	Precipitation	Runoff	Evapotranspiration	Net Infiltration/Recharge		
Cahill (1982)	46.62	0	31.62	15		
Stricker (1983)	-	-	-	14		
Hubbard and Emslie (1984)	47	2	30	15		
Hubbard (1986)	48	2	30	16		
Parizek and Root (1986)	47.78	2	30.78	15		
Hubbard and Englehardt (1987)	48.51	1.21	32.6	14.7		
Dennehy and McMahon (1989)	47.8	0	33.5	14.3		
Clarke and West (1998)	-	-	-	15.6 (New Ellenton) 14.3 (above Road C) <sup>°</sup> 10.6 (at Road A)		
Young and Pohlmann (2001)	10 years Augusta, GA data from 1977 to 1987	-	Determined but not reported in the document <sup>b</sup>	9.1		
Young and Pohlmann (2003)	10 years Augusta, GA data from 1977 to 1987	-	Determined but not reported in the document <sup>2</sup>	11.7		
Median of the ten studies <sup>d</sup>	47.79	1.6	31.2	14.5		

Table 2-1. Summary of Historical Water Balance, Infiltration, and Groundwater Recharge Field
and Modeling Studies Relevant to SRS.

<sup>a</sup> All studies assumed that the change in water storage was a negligible component in the overall water budget.

<sup>b</sup> Based on the magnitude of the infiltration rate, the associated evapotranspiration rate would be relatively high (i.e., > 30 inches/year).

<sup>c</sup> Station closest to E-Area.

<sup>d</sup> The median of the ten studies does not include precipitation, runoff, and evapotranspiration rates from Young and Pohlmann (2001, 2003), Stricker (1983), and Clarke and West (1998).

<sup>&</sup>lt;sup>2</sup> A change in soil water storage equal to +0.071 inches/year is also reported by the HELP model to satisfy the water mass balance (annual avg. precipitation = evapotranspiration +  $\Delta$  water storage + surface runoff + net infiltration).

#### 3.0 Consideration of Alternatives to the HELP Model

#### 3.1 Hydrologic Model of the SRS Saltstone Disposal Facility Closure Cap

At a September 2018 Performance Assessment Community of Practice webinar, Benson (2018) shared a hydrologic model of the planned Saltstone Disposal Facility (SDF) closure cap at SRS. The SDF model, developed by Benson and Benavides (2018), is based on current best practices for predicting long-term percolation rates through closure caps, including the recommendation by Benson et al. (2011) to employ long-term engineering properties in performance assessment hydrologic models. Relevant conclusions reached by Benson et al. (2011) were:

- "Increases in the saturated hydraulic conductivity, saturated volumetric water content, and the air entry suction (as characterized by van Genuchten's α parameter) occurred due to formation of soil structure, regardless of climate, cover design, or service life."
- "Substantial changes in hydraulic conductivity were observed in some geosynthetic clay liners (GCLs) that did not hydrate completely and underwent cation exchange."
- "Changes in geomembranes and geosynthetic drainage layers over time were modest or small, and computations based on antioxidant depletion rates suggest that the minimum service life of geomembranes is on the order of 50-125 years (the actual service life will be longer)."

Ongoing studies by Benson's research team since 2011 have led to a more optimistic outlook on long-term closure cap performance:

- An erosion layer creates a hydraulic choke that maintains nearly saturated conditions in the earthen layers below. Therefore, an assumption of unit gradient vertical flow below the erosion layer is reasonable. (Author note: This is consistent with use of a unit vertical hydraulic gradient in the HELP model and diminishes the importance of using a Richards-equation-based infiltration model in a wetter climate such as SRS.)
- Exhumed covers show minimal fines migration into lateral drainage layers, while 2000-year-old burial tombs located in humid climates in Korea and Japan show no evidence of fine- and coarselayer blending. Benson and Benavides (2018) conclude that there is no justification to assume a saturated hydraulic conductivity less than 5E-02 cm/s for the lateral drainage layer. (Author note: The E-Area LLWF PA HELP model simulations assume a steady decrease in the saturated hydraulic conductivity of the lateral drainage layer from 5E-02 cm/s at installation to 1.4E-03 cm/s beyond 2600 years due to clay fines migration from the upper backfill layer above.)
- Tian et al. (2017) investigated antioxidant depletion in HDPE geomembrane coupons immersed in synthetic low-level radioactive waste leachate; extrapolation of the experimental data suggests a total service life for HDPE geomembranes of more than 1900 years. In the SDF hydrologic model, a long geomembrane service life is accounted for by assuming a constant defect density of only five defects per hectare, which is equivalent to two approximately 1-cm<sup>2</sup> holes per acre (Giroud and Bonaparte, 1989). (Author note: The E-Area PA HELP model simulations assume a sharply increasing number of 1-cm<sup>2</sup> defects in the HDPE geomembrane layer over time, beginning with four defects per acre at the time of installation and steadily increasing to 5,496 defects per acre at 1800 years and 34,466 defects per acre at 10,000 years.)

- GCLs exhumed from composite barriers in covers at humid eastern sites (e.g., Barnwell, South Carolina) indicate that the long-term saturated hydraulic conductivity of a GCL (when located beneath a geomembrane) is less than 1E-09 cm/s, even under substantial distortion and complete cation exchange. (Author note: The E-Area PA HELP model simulations assume a saturated hydraulic conductivity for the GCL equal to 5E-09 cm/s at installation, increasing to 5E-08 cm/s thereafter.)
- Benson and Benavides (2018) also assume no loss in GCL integrity caused by root penetration. This is because "roots accumulate in regions where water is more plentiful and readily extracted, and do not grow toward regions where water is less plentiful and more difficult to extract." They report that when covers are exhumed, roots are present where water accumulates (i.e., in the soil overlying the lateral drainage layer and composite barrier). Root systems were not observed below the composite barrier in any of the cover systems evaluated by Benson et al. (2011). (Author note: The E-Area PA HELP model simulations assume that pine tree tap roots begin to penetrate each defect in the geomembrane after 200 hundred years, taking advantage of increasing water percolation through the degraded geomembrane and thereby creating holes in the GCL as well.)
- Finally, the thickness of the earthen layers above the composite barrier layer is not as important in a humid environment as it is in an arid environment, meaning that "the composite barrier formed by the geomembrane and GCL will provide the predominant resistance to flow at the base" of the SDF closure cap (Benson, 2018).

To predict long-term percolation rates for the SDF, Benson (2018) coupled WinUNSAT-H with the Giroud equations, which are analytical solutions for lateral drainage flow and composite barrier leakage. For the multilayer cover system, WinUNSAT-H models water flow in the earthen layers above the drainage layer, while the Giroud equations (Giroud and Houlihan, 1995; Giroud, 1997; Giroud et al., 2000; Giroud et al., 2004) calculate drainage layer flow and percolation through the composite barrier layer (e.g., geomembrane/GCL/finely textured foundation layer).

WinUNSAT-H (Fayer, 2000) is a FORTRAN code developed at Pacific Northwest Laboratory for simulating the one-dimensional flow of water, vapor, and heat in variably saturated soils with atmospheric interaction. Developed for the semiarid Hanford site, WinUNSAT-H simulates precipitation, evaporation, plant transpiration, storage, and deep drainage processes. The code simulates liquid water flow using the Richards equation, water vapor diffusion using Fick's law, and sensible heat flow using the Fourier equation. Unlike the HELP model, WinUNSAT-H does not include a weather generator, nor does it simulate lateral drainage and barrier layers with or without defects (holes). Any improvement in model accuracy potentially gained by switching to a Richards-equation-based model of the vadose zone, therefore, will be offset by the limitations associated with the WinUNSAT-H code as described above.

As for the SDF final closure cap, the planned E-Area LLWF final closure cap will also be located in a wetter climate and will include a composite barrier providing the predominant resistance to flow at its base. For this reason, a direct comparison was made of percolation rates through the combined lateral drainage and composite barrier layers only using the Giroud equations and the HELP model.

As derived by Giroud (1997) and presented by Benson (2018), the semi-empirical analytical solution for combined lateral drainage flow and composite liner leakage is:

$$Q = 0.976C_{qo} \left[ 1 + 0.1 \left( \frac{h_{max}}{t_b} \right)^{0.95} \right] d^{0.2} (h_{max})^{0.9} K_b^{0.74}$$
(Eqn. 1)

$$h_{max} = \frac{qL}{K_{d}\tan\beta}$$
(Eqn. 2)

where:

Q = leakage rate per geomembrane hole (m<sup>3</sup>/s per hole)

 $C_{qo}$  = contact factor = 0.21 (good placement quality)

 $h_{max}$  = maximum liquid head in drainage layer above geomembrane (m)

q = percolation rate through backfill layer above drainage layer (m/s)

L = horizontal slope length (m)

 $\beta$  = slope angle (degrees or radians)

 $K_d$  = saturated hydraulic conductivity of drainage layer (m/s)

- $K_b$  = saturated hydraulic conductivity of soil component of the composite liner (i.e., GCL only) (m/s)
- d = geomembrane defect diameter (m)

 $t_b = GCL \text{ thickness } (m)$ 

Eqn. 1 assumes that leakage through the composite barrier occurs only through defects (holes) in the geomembrane and that there is "good" contact between the geomembrane liner and the permeability-controlling soil layer below (Giroud and Bonaparte, 1989). This contrasts with the HELP model which calculates leakage through the intact portion of the geomembrane via vapor diffusion in addition to leakage through the defects. Interestingly, the HELP model also bases its predictions of leakage rate through holes in the geomembrane on the work of Giroud and Bonaparte (1989), but selects from a more complex set of empirical leakage rate equations that are chosen based on two input parameters specified by the user:

• Placement quality<sup>3</sup> (i.e., perfect, excellent, good, poor, or worst case) of the geomembrane liner on top of the low-permeability earthen layer (e.g., GCL) below. Placement quality is reflected in the value for C<sub>qo</sub> used in Eqn. 1.<sup>4</sup>

<sup>&</sup>lt;sup>3</sup> According to Schroeder (1994a), placement quality refers to the degree of contact between the geomembrane layer and the flow-limiting layer (e.g., GCL) below. Liquid passing through an assumed circular hole in the geomembrane will flow laterally between the geomembrane and the GCL unless there is either "perfect" contact between the two layers or "free flow" from the hole. The size of the space between the geomembrane and GCL depends on the roughness of the soil surface, soil particle size, rugosity and stiffness of the geomembrane, and overburden pressure. The HELP model ranks the contact between a geomembrane and GCL as perfect, excellent, good, poor, and worst case (free flow). Interfacial flow is assumed to be radial, covering a circular area called the wetted area, and is controlled by the hydraulic transmissivity of the gap between the geomembrane and the GCL. Giroud and Bonaparte (1989) examined steady-state leakage through a geomembrane liner for all these qualitative levels of contact and provided either theoretical or empirical solutions for the leakage rate and the radius of interfacial flow.

<sup>&</sup>lt;sup>4</sup> Giroud et al. (1989) established the following values for  $C_{qo}$ : 0.21 for good placement quality and 1.15 for poor placement quality.  $C_{qo}$  for excellent placement quality was not given but would be less than 0.21.

• Saturated hydraulic conductivity of the flow-controlling earthen layer (e.g., GCL).<sup>5</sup>

Because the comparison with the HELP model is focused solely on flow through the combined lateral drainage and composite barrier layers, the percolation rate from the upper backfill layer, q, in Eqn. 2 was calculated from the results of the HELP model simulations for the intact case, rather than running WinUNSAT-H. The flow from the upper backfill layer in the HELP model was determined by mass balance (units of length per time):

q (m/s) = annual avg. precipitation – evapotranspiration –  $\Delta$  water storage – surface runoff (Eqn. 3)

Table 3-1 lists the input parameter assumptions for Eqn. 1 and Eqn. 2 in metric units for the Slit and Engineered Trench intact infiltration cases. For this comparison alone, the HELP model simulations assumed a "good" placement quality<sup>6</sup> for the geomembrane layer to be consistent with the value for  $C_{qo}$  used in Eqn. 1 by Benson (2018) for the SDF closure cap design. Appendix A provides the HELP model input parameter data sheets for each time step listed in Table 3-1.

 Table 3-1. Input Parameter Assumptions for the Giroud Equations – Slit and Engineered Trench

 Intact Infiltration Cases (2% slope, 585-foot slope length).

HELP Model Intact Case	Description <sup>a</sup>	q (m/s) <sup>b</sup>	L (m) °	tan β <sup>d</sup>	K <sub>d</sub> (m/s) <sup>e</sup>	K <sub>b</sub> (m/s) <sup>f</sup>	d (m) <sup>g</sup>	t <sub>b</sub> (m) <sup>h</sup>	# holes per hectare
ST00	t = 100 yr	1.289E-08	178.308	0.02	5.00E-04	5.00E-11	0.0113	0.00508	12.4
ST01	t = 180 yr	1.282E-08	178.308	0.02	4.48E-04	5.00E-11	0.0113	0.00508	101.3
ST02	t = 290 yr	1.279E-08	178.308	0.02	3.86E-04	5.00E-10	0.0113	0.00508	239.7
ST03	t = 300 yr	1.278E-08	178.308	0.02	3.81E-04	5.00E-10	0.0113	0.00508	252.0
ST05	t = 380 yr	1.268E-08	178.308	0.02	3.41E-04	5.00E-10	0.0113	0.00508	350.9
ST06	t = 480 yr	1.269E-08	178.308	0.02	2.98E-04	5.00E-10	0.0113	0.00508	1186.1
ST07	t = 660  yr	1.258E-08	178.308	0.02	2.33E-04	5.00E-10	0.0113	0.00508	2757.7
ST08	t = 1,100  yr	1.211E-08	178.308	0.02	1.28E-04	5.00E-10	0.0113	0.00508	6597.7

<sup>a</sup> Relative time (t): 100 yr is the end of institutional control when the final closure cap is installed.

<sup>b</sup> Calculated from HELP model results for intact cases using Eqn. 3.

<sup>c</sup> Slope length for bounding intact case is 178.308 m (585 feet).

<sup>d</sup> Slope angle,  $\beta$ , is 1.1458 degrees or 0.02 radians.

<sup>e</sup> K<sub>d</sub> of drainage layer (5E-04 m/s) decreases over time due to silting in from the backfill layer above.

<sup>f</sup> K<sub>b</sub> of GCL layer equals 5E-11 m/s at t = 100 yr and 180 yr and decreases to 5E-10 m/s at t > 180 yr.

<sup>g</sup> Diameter of 1E-04 m<sup>2</sup> (1 cm<sup>2</sup>) hole.

<sup>h</sup> Thickness of GCL is 0.00508 m (0.20 inches).

Table 3-2 displays a side-by-side comparison of total leakage rates ( $Q_{tot}$ ) through the composite barrier as predicted by the HELP model and the Giroud equations for the E-Area Slit-and-Engineered-Trench intact case. Agreement between the two models is good through relative Year 380 (Case ST05) when the

 $<sup>^{5}</sup>$  The HELP model designates the controlling soil layer (GCL) as either high, medium, or low permeability, where high is a saturated hydraulic conductivity greater than or equal to 1E-03 m/s, medium is greater than or equal to 1E-06 m/s and less than 1E-03 m/s, and low is less than 1E-06 m/s. The low permeability layers are assumed to remain saturated in the wetted area throughout the HELP model simulation.

<sup>&</sup>lt;sup>6</sup> Intact infiltration rate calculations for the E-Area LLWF PA closure cap assume an "excellent" placement quality for the geomembrane layer. Predicted infiltration rates are quite sensitive to the placement quality assumption. For example, infiltration rates predicted by the HELP model are 1.1X to 6.5X lower when an excellent versus a good placement quality is assumed.

number of defects (holes) in the geomembrane is small. Beyond relative Year 380, the difference in predicted infiltration rates by the two models increases significantly with the Giroud equations calculating a much larger percolation rate through the geomembrane defects. This difference is likely due to several factors:

- When used outside a mass-balance model such as HELP, the Giroud equations are not constrained by the conservation of mass. For example, at relative Year 660 and later, the percolation rates predicted by the Giroud equations exceed the liquid supply rates from the backfill layers above. Conversely, the HELP code ensures that total leakage through the geomembrane and controlling layers is not greater than the total volume of drainable water. The HELP code also checks to make certain that the leakage rate is not greater than the product of the hydraulic gradient and the saturated hydraulic conductivity of the controlling GCL layer (Schroeder et al. 1994a).
- The Giroud equations as implemented by Benson (2018) in Eqn. 1 for the SDF closure cap design utilize the maximum hydraulic head acting on the geomembrane layer to calculate the leakage rate through each hole. On the other hand, the HELP code uses the slope-length-averaged hydraulic head at each time step (1 day) for 100 years of simulated daily precipitation data.
- Giroud and Bonaparte (1989) and Giroud et al. (1992) developed their leakage rate equations for intact geomembranes, geomembranes surrounded by high-permeability materials, and composite liners (i.e., drainage layer/geomembrane/low-permeability soil liner) assuming relatively low defect densities (i.e., less than 10 to 20 defects per acre) characteristic of modern equipment, materials, and installation and QA/QC practices (Schroeder et al., 1994a; Schroeder et al., 1994b). Conversely, the closure cap degradation model for the E-Area LLWF assumes a much greater defect density that increases linearly with time (i.e., 141, 479, and 1115 defects per acre at relative Years 380, 480, and 660, respectively).

For these collective reasons, poor agreement between the standalone Giroud equations and the HELP mass-balance model at high defect densities is not surprising.

HELP Model Intact Case	Description <sup>a</sup>	Giroud Equation h <sub>max</sub> (m)	Giroud Equation Q <sub>tot</sub> (mm/yr)	HELP Model Q <sub>tot</sub> (mm/yr) <sup>b</sup>	Ratio HELP:Giroud
ST00	t = 100 yr	0.23	0.098	0.102	1.04
ST01	t = 180 yr	0.26	0.95	1.11	1.17
ST02	t = 290 yr	0.30	15.86	17.37	1.10
ST03	t = 300 yr	0.30	17.04	18.59	1.09
ST05	t = 380 yr	0.33	28.22	32.68	1.16
ST06	t = 480 yr	0.38	120.34	86.65	0.72
ST07	t = 660 yr	0.48	421.25 °	158.82	0.38
ST08	t = 1,100  yr	0.84	2708.45 °	240.10	0.09

 

 Table 3-2. Comparison of HELP Model Results to Giroud Equation – Slit and Engineered Trench Intact Cases (2% slope, 585-foot slope length).

<sup>a</sup> Relative time (t): 100 yr is the end of institutional control when the final closure cap is installed.

<sup>b</sup> For this comparison, HELP model results assume a good, rather than an excellent, geomembrane placement quality.

<sup>c</sup> Q<sub>tot</sub> exceeds the liquid supply rate, q. Liquid supply rate is 397 mm/yr at 660 yr and 382 mm/yr at 1,100 yr.

#### 3.2 Comparison of HYDRUS-1D to the HELP Model

HYDRUS-1D (Šimůnek et al., 2013) is a public-domain, Windows-based modeling environment which utilizes a one-dimensional finite element model (HYDRUS) to simulate the movement of water, heat, and one or more solutes in variably-saturated porous media. For saturated-unsaturated water flow, HYDRUS employs the Richards equation, which is modified to include a sink term for water uptake by plant roots. According to Šimůnek et al. (2013), the flow zone may consist of heterogeneous soil types, while flow and transport can occur vertically, horizontally, or in a generally inclined direction. The user can specify constant or time-varying prescribed head and flux boundaries, boundaries controlled by atmospheric conditions, or free-drainage boundary conditions. Soil surface boundary conditions can change during the simulation from prescribed flux to prescribed head-type conditions (and vice versa). Unsaturated soil hydraulic properties are described using van Genuchten, Brooks and Corey, and modified van Genuchten-type analytical functions, while root growth is simulated with a logistic growth function. The model does not include a synthetic weather generator.

#### 3.2.1 Published Case Studies

Pontedeiro et al. (2013) selected HYDRUS-1D to model water flux through a municipal solid waste landfill in Rio de Janeiro, Brazil. Two different cover systems were considered: a capillary barrier made from municipal solid waste compost and an evapotranspiration cover using grass or native vegetation. Hydraulic parameters for the cover soil were estimated using the Rosetta pedotransfer functions<sup>7</sup> in HYDRUS-1D and measured soil texture data for the fines. In all simulations, the thickness of the operational and final soil cover layers was 60 centimeters, while the municipal waste layer was 500 centimeters. The cover design included no erosion, lateral drainage, or geosynthetic barrier layers. The model was calibrated by simulating each vertical landfill cell separately and then summing the individual deep drainage rates from each cell. The sum was compared to the estimated recharge rate for the aquifer based on local weather data and potential evapotranspiration rates calculated with the Hargreaves (1975) equation. The deep drainage volume predicted by HYDRUS-1D during 2010 was 27,020 m<sup>3</sup> compared to a measured volume of 33,100 m<sup>3</sup>. A capillary barrier layer of 30 to 50 centimeters reduced the drainage water flux by approximately 40 percent compared to a compacted surface soil. Similarly, a vegetative cover lowered the drainage water flux by 34 percent for grass and 48 percent for the native *brachiaria*.

Worthy et al. (2011) compared the performance of the HELP, HYDRUS-1D, and WinUNSAT-H models in simulating the expected hydrologic performance of a capillary barrier cover system for the uranium mill tailings disposal facility in Monticello, Utah. The actual four-layer cover system (fine-textured soil and rock water storage layer, sand capillary barrier layer, HDPE geomembrane layer, and lowpermeability compacted soil liner) was modeled for simplicity as a single 1,100-millimeter-thick soil layer with equivalent hydraulic properties matching field conditions at the repository. Worthy et al. (2011) noted that "HELP is the only landfill-specific water balance model available." Three climate scenarios were considered for each model: a typical temporal year (annual-average precipitation), a design temporal year (maximum precipitation), and a future synthetic-analogue year based on a general circulation climate model. Daily precipitation and temperature data from the Utah State University Climate Center database were used in all three models for the Scenario 1 (typical year) and Scenario 2 (design year) simulations. Conversely, the HELP model's synthetic weather generator used monthlyaverage precipitation and temperature data to generate (1) the daily precipitation and temperature data for

<sup>&</sup>lt;sup>7</sup> Pedotransfer functions are predictive functions of certain soil properties using data from soil surveys.

the Scenario 3 (synthetic analogue year) simulations for all three models, and (2) the synthetic daily solar radiation data for all three models for the three simulation scenarios. Despite the single-layer simplification, results varied significantly among the three models. For the HELP model, predicted changes in evapotranspiration, runoff, percolation, and water storage for the three climate scenarios were modest and trended in the directions expected. The WinUNSAT-H model predicted much higher surface runoff and percolation rates than HELP and HYDRUS-1D due to a large, negative change in water storage. In addition, percolation rates predicted by WinUNSAT-H decreased from Scenario 2 to Scenario 3, while they increased for both HELP and HYDRUS-1D. With HYDRUS-1D, differences in the percolation rate and water storage among the three scenarios were larger and less predictable. Compared to HELP, HYDRUS-1D predicted much higher percolation rates, partly because HYDRUS-1D calculated zero surface runoff for all three scenarios.

Meadows and Waite (2016) used HYDRUS-1D to simulate the hydrologic performance of a proposed alternative evapotranspiration cover for the Salt Lake Valley Landfill in Utah. The cover system was designed to store water that infiltrates into the cover material and to remove it via transpiration and evaporation before percolating into the underlying waste. The cover system uses the water-storage capacity of the soil layers, rather than the lower-permeability physical characteristics of a geomembrane or GCL, to minimize infiltration. The proposed evapotranspiration cover system design included three to four feet of vegetated, fine-grained (i.e., silty to clayey loam) soil to provide moisture storage capacity above the buried waste. Meadows and Waite (2016) evaluated three sets of hydraulic properties for the final cover soil at two different cover thicknesses each. Daily climate data representing the five consecutive wettest years on record were used. Two hydraulic properties sets were based on site-specific values for on-site materials that could be used for the evapotranspiration cover, while the third set represented weathered values for fine-grained soils. HYDRUS-1D model results for all three hydraulic properties sets indicated that a four-foot cover thickness will limit water flux through the base of the evapotranspiration cover to less than three millimeters per year.

#### 3.2.2 E-Area LLWF Comparison Cases

Table 3-3 lists the E-Area LLWF closure cap cases included in a side-by-side comparison of the HYDRUS-1D and HELP models. Comparison cases were limited to earthen multilayer systems only (the lone exception being the institutional control case) for several reasons:

- HYDRUS-1D is fundamentally an agricultural modeling tool designed to simulate water and solute transport in variably-saturated porous media composed of nonuniform soils. For example, there is no mechanism to include a geomembrane/GCL barrier layer with an assumed defect density.
- HYDRUS-1D includes a lower boundary condition that simulates horizontal drainage representative of a tile drainage system<sup>8</sup> and assumes an impermeable layer at the base. Unfortunately, the tile drainage model is not representative of a multilayer cover system with a separate lateral drainage layer above and free drainage at the base below. As a result, the tile

<sup>&</sup>lt;sup>8</sup> A tile drainage system consists of a network of belowground pipes called laterals and mains that function to manage the water table. Laterals are spaced throughout the field to collect water that then drains to a main. The main allows the system to transport the water away from the field in a controlled manner. The tile drainage system is designed on a grade so water flows in the desired direction.

drainage model outputs the total drainage from a multilayer soil column (i.e., the sum of horizontal drainage and any vertical drainage from the permeable soil layers below the lateral drainage layer).

• The Richards equation, which is used in HYDRUS-1D to model variably-saturated flow, makes model convergence more challenging. This is particularly true for layered systems comprised of materials with widely varying porosities and saturated hydraulic conductivities (e.g., a low-permeability composite geomembrane/GCL sandwiched between permeable earthen layers). Conversely, model convergence is rarely an issue with a mass balance model such as HELP.

Screen captures of the input parameter templates used in the HYDRUS-1D model simulations for Cases 3-1 through 3-4 are displayed in Appendix B. Appendix C contains screen captures from HYDRUS-1D of the boundary water fluxes of interest for comparison to the HELP model results. Summaries of the HELP/HYDRUS-1D side-by-side comparisons are shown in Table 3-4, Table 3-5, Table 3-6, and Table 3-7 for Cases 3-1, 3-2, 3-3, and 3-4, respectively. All results are reported as annual-average values.

Table 3-4 presents the results for the single-layer operational soil cover case. Agreement between the HYDRUS-1D and HELP models is satisfactory when daily time steps were used in the HYDRUS-1D simulation (by default, the HELP model uses daily weather data and a daily time step). Because HYDRUS-1D does not include a weather generator, both annual-average and daily weather data were exported from HELP to be used in the HYDRUS-1D simulations. The predicted percolation rate through the operational soil cover layer is 15.78 inches/year per the HELP model and 14.8 inches/year per HYDRUS-1D, a difference of 0.98 inches/year or -6.2% relative to the HELP model result.

Results for the two-layer institutional control case (HDPE stormwater runoff cover overlying a four-footthick operational soil cover) are displayed in Table 3-5. Two subcases for the HDPE cover were considered in the HYDRUS-1D simulations:  $K_{sat}$  equal to 5.0E-08 cm/sec (same value as used in the HELP model simulations) and  $K_{sat}$  equal to 1.0E-09 cm/sec. In both cases, HYDRUS-1D predicts substantially more evapotranspiration (transpiration is zero because there is no vegetative cover) than the HELP model and, therefore, less surface run-off. For an assumed  $K_{sat HDPE}$  of 5.0E-08 cm/sec, HYDRUS-1D calculates a percolation rate at the base of the soil column equal to 0.71 inches/year, which is approximately eight times higher than the HELP model prediction of 0.089 inches/year. If  $K_{sat HDPE}$  is reduced to 1.0E-09 cm/sec in the HYDRUS-1D model only, agreement between the HELP and HYDRUS-1D models is improved.

Table 3-6 summarizes results for the top three earthen layers in the proposed E-Area LLWF closure cap design at the time of installation: six-inch topsoil layer, 30-inch upper backfill layer, and 12-inch erosion barrier. The same material properties values assumed for the three layers in the HELP model simulations were also used in the HYDRUS-1D model simulations. HYDRUS-1D predicts more surface runoff and evapotranspiration than the HELP model; therefore, the percolation rate at the base of the soil column is approximately five inches/year lower for HYDRUS-1D than HELP.

Table 3-7 displays the results for the top four layers in the proposed E-Area LLWF closure cap design at the time of installation: six-inch topsoil layer, 30-inch upper backfill layer, 12-inch erosion barrier, and 12-inch lateral drainage layer. The same material properties values assumed for the top four layers in the

Table 3-3. E-Area LLWF Infiltration Scenarios used in the HELP and HYDRUS-1D Side-by-Side
Comparison.

Comparison Case	Infiltration Scenario	Description		
		Four-foot soil cover for Slit Trench installed at end of operations <sup>a</sup>		
		(a) Annual rainfall data; (b) Daily rainfall data		
3-1a	Operational Soil Cover	Grass sover with active root growth		
3-10		Atmospheric upper boundary condition with surface		
		runoff		
		Free drainage lower boundary condition		
		HDPE geomembrane overlying four-foot soil cover for Slit Trench installed at end of operations <sup>a</sup>		
		(a) $K_{sat HDPE} = 5.0E-08 \text{ cm/s}$ ; (b) $K_{sat HDPE} = 1.0E-09 \text{ cm/s}$		
	Institutional Control (HDPE)	Minimal (0.1 cm) soil layer on top of HDPE to enable HELP model execution		
3-2a 3-2b		Daily rainfall data		
		100-year simulation period		
		No root growth		
		Atmospheric upper boundary condition with surface runoff		
		Free drainage lower boundary condition		
		Topsoil, Upper Backfill, and Erosion Barrier layers		
		Daily rainfall data		
	Upper Three Layers of	100-year simulation period		
3-3	Intact Multilayer Cover	Grass cover with active root growth		
	(at instantation)	Atmospheric upper boundary condition with surface runoff		
		Free drainage lower boundary condition		
		Topsoil, Upper Backfill, Erosion Barrier, and Lateral Drainage layers		
	Han on Found arrange of	Daily rainfall data		
3-4	Intact Multilaver Cover	100-year simulation period		
	(at installation)	Grass cover with active root growth		
	(	Atmospheric upper boundary condition with surface runoff		
		Horizontal deep-drainage lower boundary condition		

<sup>a</sup> A relative comparison between the two models was made assuming a minimum uniform four-foot-thick clean soil layer. In practice, the soil layer thickness will be greater than four feet and the soil will be sloped away from the centerline (crest) to obtain positive drainage toward the edges.

Modeled Flux	HELP Model (Daily Rainfall)	Case 3-1a HYDRUS-1D (Annual Rainfall)	Case 3-1a Difference (Annual Rainfall)	Case 3-1b HYDRUS-1D (Daily Rainfall)	Case 3-1b Difference (Daily Rainfall)
Precipitation (inches/year)	49.14	49.08	-0.06	48.98	-0.16
Runoff (inches/year)	0.029	0.00	-0.03	0.00	-0.03
Evapotranspiration (inches/year)	33.27	29.50	-3.77	34.18	0.92
Percolation Rate (inches/year)	15.78	19.58	3.80	14.80	-0.98

Table 3-4. Case 3-1 – Operational Soil Cover – Comparison of HYDRUS-1D and HELP Model Predictions.

Table 3-5. Case 3-2 – Institutional Control (HDPE Cover) – Comparison of HYDRUS-1D and HELP Model Predictions.

Modeled Flux	HELP Model	Case 3-2a HYDRUS-1D (K <sub>sat</sub> = 5.0E-08 cm/s)	Case 3-2a Difference (K <sub>sat</sub> = 5.0E-08 cm/s)	Case 3-2b HYDRUS-1D (K <sub>sat</sub> = 1.0E-09 cm/s)	Case 3-2b Difference (K <sub>sat</sub> = 1.0E-09 cm/s)
Precipitation (inches/year)	49.14	48.34	-0.80	49.04	-0.10
Runoff (inches/year)	48.98	36.09	-12.90	37.87	-11.11
Evapotranspiration (inches/year)	0.066	11.54	11.47	11.12	11.05
Percolation Rate (inches/year)	0.089	0.71	0.62	0.044	-0.045

Modeled Flux	HELP Model (at installation)	Case 3-3 HYDRUS-1D	Case 3-3 Difference			
Precipitation (inches/year)	49.14	48.94	-0.20			
Runoff (inches/year)	0.002	0.62	0.62			
Evapotranspiration (inches/year)	32.54	36.47	3.93			
Percolation Rate (inches/year)	16.57	11.85	-4.72			

#### Table 3-6. Case 3-3 – Upper Three Layers of Intact Multilayer Cover – Comparison of HYDRUS-1D and HELP Model Predictions.

 Table 3-7. Case 3-4 – Upper Four Layers of Intact Multilayer Cover –

 Comparison of HYDRUS-1D and HELP Model Predictions.

Modeled Flux	HELP Model (at installation)	Case 3-4 HYDRUS-1D	Case 3-4 Difference		
Precipitation (inches/year)	49.14	49.35	0.21		
Runoff (inches/year)	0.002	0.60	0.60		
Evapotranspiration (inches/year)	32.54	36.93	4.39		
Percolation Rate (inches/year)	16.57	11.82	-4.75		

HELP model simulations were also used in the HYDRUS-1D model simulations. As noted above, HYDRUS-1D includes the choice of a lower boundary condition for horizontal drainage that simulates a tile drainage system only and assumes an impervious layer at the base. This substantially limits its applicability to the E-Area cap design because the PA infiltration conceptual model assumes degradation and, hence, increasing permeability of the geomembrane/GCL barrier layers with time. Agreement between the HELP model and HYDRUS-1D is the same as for Case 3-3.

Simulation cases that included a low-permeability geomembrane and/or GCL barrier layer below the lateral drainage layer were tested in HYDRUS-1D; however, numerical convergence was not achieved.

#### Conclusions

The HELP model remains the preferred choice over other commercial and public-domain hydrologic models for the E-Area LLWF PA for the following reasons:

- Benson and Benavides (2018) coupled the Richards-equation-based, one-dimensional WinUNSAT-H model with the Giroud equations to simulate the multilayer SDF cover system because WinUNSAT-H cannot simulate flow through lateral drainage and barrier layers. WinUNSAT-H was used to model water flow in the earthen layers above the lateral drainage layer, while the Giroud equations calculated drainage-layer flow and percolation through the composite barrier layer (i.e., geomembrane/GCL/finely textured foundation layer). Like the SDF, the E-Area LLWF is also located in a wetter climate and its final closure cap design will include a composite barrier providing the predominant resistance to flow at its base. As a result, any improvement in accuracy gained by switching to a Richards-equation-based model of the vadose zone is largely offset in a wet climate by the need to couple WinUNSAT-H, HYDRUS-1D, or HYDRUS-2D3D with a separate model for the drainage and barrier layers.
- The HELP model bases its predictions of leakage rate through holes in the geomembrane barrier layer on the same family of semi-empirical Giroud equations mentioned above. The HELP model selects from a set of empirical leakage rate equations developed originally by Giroud and Bonaparte (1989) that are chosen based on two user-specified input parameters: placement quality of the geomembrane and saturated hydraulic conductivity of the flow-controlling GCL below the geomembrane. If "good" placement quality and low to moderate defect density are assumed, the Giroud equations (as implemented by Benson and Benavides (2018) for the SDF cap) predict a leakage rate through the barrier layer that is in close agreement with the leakage rate predicted by the HELP model for the same cap design. The leakage rate is quite sensitive to the placement quality assumption.
- The cap degradation and subsidence scenarios for the E-Area LLWF closure cap necessitate a flexible, robust infiltration model that readily converges over a wide range of assumed cap and material design properties and conditions. The Richards equation is inherently unstable; therefore, obtaining a numerical solution can be a challenge. Whiteside et al. (2009) noted convergence challenges with sandy-clay soils under high-rainfall conditions typical of SRS. Despite its limitations, the HELP model excels in this regard over models using the Richards equation for variably-saturated flow, which includes WinUNSAT-H, HYDRUS-1D, and HYDRUS-2D3D. For example, the coupled WinUNSAT-H/Giroud equation model used by Benson and Benavides (2018) gave unrealistic predictions for leakage rate through the composite barrier as the number of assumed defects in the geomembrane layer exceeded on the order of 1,000 holes per hectare.
- Benson and Benavides (2018) showed that the erosion barrier in the SDF and E-Area LLWF closure cap designs will create a hydraulic choke that maintains nearly saturated conditions in the earthen layers below. Therefore, an assumption of unit gradient vertical flow below the erosion layer is reasonable and consistent with the use of a unit vertical hydraulic gradient in the HELP model, which diminishes the importance of using a Richards-equation-based infiltration model in a wetter climate such as SRS.

- The HELP model contains an internal weather generator that creates synthetic daily weather data for long-term simulations (e.g., 100 years) using historical monthly-average precipitation, temperature, and solar radiation data. WinUNSAT-H and the HYDRUS software do not include a synthetic weather generator, which makes data entry more cumbersome and limited to the availability of historical daily data.
- Sensitivity studies by Shipmon and Dyer (2017) using the HELP model identified the primary drivers for the predicted infiltration rate for the F-Area Tank Farm closure cap design. The primary drivers include the degradation rate of the geomembrane liner (number of holes per unit area vs. time), the silting-in rate of the lateral drainage layer, the rate of pine tree intrusion and associated root penetration through the GCL, and the size and location of subsided areas due to non-crushable containers disposed in slit and engineered trenches. The primary drivers change the infiltration rate by more than four orders of magnitude over a 10,000-year period. In contrast, this evaluation concludes that the choice of one hydrologic model over another is only a secondary driver of predicted infiltration rates (i.e., differences among WinUNSAT-H, HYDRUS-1D, and HELP model predictions for the same scenario are less than one order of magnitude).

In summary, the HELP model was designed specifically to simulate infiltration through multilayer closure-cap systems, and it remains the best option for modeling such systems in wet climates where a unit hydraulic gradient is a reasonable assumption. As a mass-balance model, HELP is well suited for PA evaluations where flexibility in the model framework and ease of model convergence are important. Existing hydrologic models that use the Richards equation for variably-saturated flow, on the other hand, are not designed specifically for multilayer landfill cover systems, are more difficult to converge, and often must be coupled with a second model for drainage and composite barrier layers. Although computational codes that solve the Richards equation are more sophisticated than HELP, they can be challenging to use with a high level of accuracy when percolation rates are very low and extend over long periods (Whiteside et al., 2009). One reason cited by Whiteside et al. (2009) is that mass-balance errors associated with the numerical model simulations are of the same order of magnitude as the percolation rates themselves.

The WinUNSAT-H and HYDRUS programs are better suited instead for simulating evapotranspiration cover systems typically found in arid and semi-arid climates. Evapotranspiration cover systems rely on the ability of a soil layer to store precipitation until it is naturally evaporated or transpired by a vegetative cover (U.S. EPA, 2011). This contrasts with more conventional cover systems that are engineered with a composite barrier layer of low hydraulic conductivity.

#### 4.0 Quality Assurance

A technical review of this report was performed consistent with the E7 Manual, procedure 2.60 as outlined in the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.

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Appendix A. HELP Model Input Parameters for Slit-and-Engineered-Trench Cases used in Comparisons with the Giroud Equations This Page Intentionally Blank

Input P	Gen	Generic Input Parameter Value													
Landfill area = 0.2								0.2686 acres							
Percent	100%														
Do you	Y	Y													
Amount of water or snow on surface = 0 ir									) inches						
CN Inp	CN	CN Input Parameter Value													
Slope =	2 %														
Slope le	585 ft														
Soil Te	4 (HELP model default soil texture)														
Vegetation =								4 (i.e., a good stand of grass)							
HELP I	Model Co	omputed Curve	Nur												
Laver			Lav	ver Nun	ıber		Laver Type								
Topsoil			1					1 (vertica	al pe	rcolatio	n lave	r)			
Upper	Backfill		2					1 (vertica	al pe	rcolatio	n lave	r)			
Erosior	Barrier		3					1 (vertic	al pe	rcolatio	n lave	r)			
Lateral	Drainage	e Laver	4					2 (lateral	l dra	inage la	ver)	-)			
HDPE	Geomem	brane	5					4 (geome	embi	ane line	er)				
GCL			6					3 (barrie	r soi	l liner)					
Founda	tion Lave	er (1E-06)	7					1 (vertical percolation laver)							
Founda	tion Lave	er (1E-03)	8					1 (vertice	al pe	rcolatio	n lave	r)			
Laver	Laver	Laver	Sc	oil	Total		Field	d Wilting It				nitial			
#	Type	Thickness	Te	exture	Poros	sitv	Capacity		Poi	Point N		Ioisture <sup>2</sup>			
	21	(in)	No	0.	(Vol/Vol)		(Vo	l/Vol) (Vo		ol/Vol) (		Vol/Vol)			
1	1	6			0.396		0.10	).109		0.047		.109			
2	1	30			0.35		0.25	2	0.1	81	0	.252			
3	1	12			0.15		0.1		0.0	7	0	.1			
4	2	12			0.417		0.04	5	0.0	18	0	.045			
5	4	0.06													
6	3	0.2			0.75		0.74	.7	0.4		0	.75			
7	1	12			0.35		0.252		0.181 (		0	.252			
8	1	72			0.457	7	0.13	1 0.058			0.131				
Layer	Layer	Sat. Hyd.		Draina	ge	Drain		Leachate	e Recirc. to Sub			Subsurface			
#	Туре	Conductivity	,	Length	n	Slope	Recirc. Layer		Inflow						
	~ 1	(cm/sec)		(ft)		(%)		(%)		(#)		(in/yr)			
1	1	3.1E-03													
2	1	4.1E-05													
3	1	1.3E-04													
4	2	5.0E-02		585	85 2										
5	4	2.0E-13													
6	3	5.0E-09													
7	1	1.0E-06													
8	1	1.0E-03													
Layer	Layer	Geomembra	ne	G	eomen	nbrane Ins	stal.	Geomembrane				extile			
#	Туре	Pinhole Dens	sity	D	efects			Placement Quality Tran				smissivity			
	~ 1	(#/acre)	2	(#	/acre)		(cm <sup>2</sup> /sec)				/sec)				
5	4	1	4				3			*					

## Table A-1. HELP Model Input Data for Year 100<br/>(ST00.D10).

Input Parameter (HELP Model Query) Gen									Generic Input Parameter Value						
Landfill area = $0.2$								0.2686 acres							
Percent of area where runoff is possible = $10$								100%							
Do you want to specify initial moisture storage? (Y/N) Y															
Amount of water or snow on surface = 0 in									0 inches						
CN Inp	CN	Input Para	amet	er Value	e										
Slope =		2 %													
Slope l		585 ft													
Soil Texture =								4 (HELP model default soil texture)							
Vegetation =								4 (i.e., a good stand of grass)							
HELP	mber														
Layer		•	La	yer N	umber			Layer T	ype						
Topsoi	1		1	0				1 (vertic	alp	ercolatio	on lave	er)			
Upper	Backfill		2					1 (vertic	alp	ercolatio	on lav	er)			
Erosior	Barrier		3					1 (vertic	al n	ercolatio	n lav	er)			
Lateral	Drainage	e Laver	4					2 (latera	l dra	inage la	ver)				
HDPE	Geomem	brane	5					4 (geom	emb	rane line	er)				
GCL			6					3 (barrie	er so	il liner)					
Founda	tion Lav	er (1E-06)	7					1 (vertic	al n	ercolatio	n lav	er)			
Founda	tion Lay	r(1E-03)	8					1 (vertical percolation layer)							
Laver	Laver	ver Laver Soil Total						d	(nitial						
#	Type	Thickness	T	'extur	e Poro	sitv	Can	Capacity Point			1	Moisture <sup>2</sup>			
	1990	(in)	N	lo	(Vol	/Vol)	(Vo	l/Vol) (Vol/Vol)		(	(Vol/Vol)				
1	1	5.96	1		0 396		0.10	1000000000000000000000000000000000000		047 (		) 109			
2	1	30			0.35	0	0.24	52	0.181		(	) 252			
3	1	12			0.15		0.1	2	0.0	)7	(	) 1			
4	2	12			0.13	6	0.04	18	0.0	)21	(	0.1			
5	4	0.06			0.11	0	0.0	10	0.0	21		5.010			
6	3	0.00			0.75		0.74	17	0.4	1	(	0.75			
7	1	12			0.75		0.74	0.252 0.181		181	(	) 252			
8	1	72			0.35	7	0.2	<u>1 0.181</u>				) 131			
Lover	I	Sat Hyd		Droi	0. <del>1</del> J	Drain	0.1.	Leochote	0.0	Decirc	to	Subcurface			
Hayer	Type	Sat. Hyu.	,	Long	nage	Slope	Paciro Lavar			Lover	July Subsultace				
π	rype	(cm/sec)	/	(ff)	gui	(%)		(%)	(+)			(in/yr)			
1	1	2 1E 02		(11)		(70)		(70)		(#)		(III/yI)			
2	1	1 1E-05													
2	1	4.1E-03													
 	2	1.3E-04 1.48E 02	595 2												
5	<u> </u>	2 0E_12		505		2									
6	3	5.0E-09													
7	1	1.0E-09													
/ Q	1	1.0E-00	.UE-U0 0E 03												
0 Lover	I L aver	Coomambus	<b>n</b> 0	L	Gaamaa	hrong I.:	ata1	Gaeman	hrai		Car	tartila			
Layer	Layer	Dinholo D			Geomembrane Instal.			Decement Quality				Geotextile			
# Type Pinhole Density				Defects (#/aara)			Placement Quality				1  ransmissivity				
5	4	(#/acre)			$\frac{(\#)acre}{40}$		(cm <sup>-</sup> /sec)				/800)				
5	4	1 40						5							

## Table A-2. HELP Model Input Data for Year 180(ST01.D10).

Input Parameter (HELP Model Query)								Generic Input Parameter Value							
Landfill area =								586 acres							
Percent of area where runoff is possible =								100%							
Do you	sture st	Y													
Amoun	ce =	0 inches													
CN Inp	l Query	CN Input Parameter Value													
Slope =		2%													
Slope le		585 ft													
Soil Texture =								4 (HELP model default soil texture)							
Vegetation =								4 (i.e., a good stand of grass)							
HELP I	Model Co	mber =													
Laver Laver Number								Laver Type							
Topsoil			1	-				1 (vertica	al p	ercolatio	on lay	er)			
Upper l	Backfill		2					1 (vertica	al p	ercolatio	n lay	er)			
Erosion	Barrier		3					1 (vertica	al p	ercolatio	n lay	er)			
Lateral	Drainage	e Layer	4					2 (lateral	l dra	ainage la	yer)				
HDPE	Geomem	brane	5					4 (geome	emb	orane line	er)				
GCL			6					3 (barrie	r so	il liner)					
Founda	tion Laye	er (1E-06)	7					1 (vertica	al p	ercolatio	on lay	er)			
Founda	tion Laye	er (1E-03)	8					1 (vertica	1 (vertical percolation layer)						
Layer	Layer	Layer	S	oil	Total	l	Fiel	d Wilting			]	nitial			
#	Туре	Thickness	Texture Porosity				Capacity Point			1	Moisture <sup>2</sup>				
		(in)	No. (Vol/Vol)			/Vol)	(Vo	l/Vol) (Vol/Vol)		(	(Vol/Vol)				
1	1	5.90			0.396		0.10	0.109		0.047		0.109			
2	1	30			0.35		0.252		0.181		(	0.252			
3	1	12			0.15		0.1		0.07		(	).1			
4	2	12			0.414	4	0.05	52	0.0	024	(	0.052			
5	4	0.06					0.545								
6	3	0.2			0.75		0.74	0.747 0.4			0.75				
7	1	12			0.35		0.25	.252 0.181			0.252				
8	1	72			0.457	7	0.13	31 0.058			(	0.131			
Layer	Layer	Sat. Hyd.		Drain	age	Drain		Leachate Recirc			c. to Subsurface				
#	Туре	Conductivity		Lengt	h	Slope		Recirc. Layer			Inflow				
	-	(cm/sec)		(ft)		(%)		(%)		(#)		(ın/yr)			
	1	3.1E-03													
2	1	4.1E-05													
3	1	1.3E-04		505		2									
4	2	3.86E-02		585		2									
5	4	2.0E-13													
0	5	5.0E-08													
/	1	1.0E-06	E-06												
ð	I I	1.0E-03			1	т	4-1	Car	1		C	44 <sup>1</sup> 1 -			
	Layer	Geomembrar	ne		beomen	norane In	stal.	Geomem	brai	ne	Geo	textile			
Ŧ	1 ype	(#/agra)	1sity Defects				Placement Quality				Transmissivity				
5	4	(#/acre)		(1	$\frac{+}{acre}$						/sec)				
Э	4	1	9		5										

## Table A-3. HELP Model Input Data for Year 290<br/>(ST02.D10).
Input P	Input Parameter (HELP Model Query)							Generic Input Parameter Value					
Landfil	$1 \operatorname{area} =$		' Yu	~ry)			0.2686 acres						
Percent	of area y	where runoff is	nos	ssible	=		100	%					
Do you	want to	specify initial	moi	sture	storage?	(Y/N)	Y	70					
Amoun	t of wate	r or snow on s	urfa	ce =	storuge.	(1/1()	0 in	ches					
CN Inn	ut Param	eter (HELP M	ode	l Oue	rv)		CN Input Parameter Value						
Slope =	=		040	1 240			2%						
Slope l	enoth =						585 ft						
Soil Texture =							4 (F	IELP mod	el d	efault so	il text	ure)	
Vegetation =						4 (i	e a good	star	d of gra	ss)			
HELP	Model Co	omputed Curve	e Nu	mber	= 46.2		. (1	, <i>a</i> <u>B</u> eea					
Layer Lay				aver Number				Laver T	vne				
Topsoil 1				<i>j</i>				1 (vertic	al p	ercolatio	n lav	er)	
Upper	Backfill		2					1 (vertic	al p	ercolatio	n lav	er)	
Erosior	Barrier		3					1 (vertic	al p	ercolatio	n lav	er)	
Lateral	Drainage	e Laver	4					2 (latera	l dra	ainage la	ver)	)	
HDPE	Geomem	brane	5					4 (geom	emb	rane line	er)		
GCL			6					3 (barrie	er so	il liner)			
Founda	tion Lay	er (1E-06)	7					1 (vertic	1 (vertical percolation layer)				
Founda	tion Lay	er (1E-03)	8					1 (vertic	al p	ercolatic	on lay	er)	
Layer	Layer	Layer	S	oil	Tota	.1	Fiel	d	Ŵ	ilting	]	Initial	
#	Туре	Thickness	Т	extur	e Porc	sity	Cap	acity	Po	oint	1	Moisture <sup>2</sup>	
		(in)	N	No. (Vol/Vol)				l/Vol)	(V	ol/Vol)	(	(Vol/Vol)	
1	1	5.90			0.39	6	0.10	)9	0.0	047	(	0.109	
2	1	30			0.35		0.25	52	0.	181	(	0.252	
3	1	12			0.15		0.1		0.0	)7	(	).1	
4	2	12			0.41	4	0.05	53	0.0	)24	(	0.053	
5	4	0.06											
6	3	0.2			0.75		0.74	47	0.4	1	(	).75	
7	1	12			0.35		0.25	52	0.	181	(	).252	
8	1	72		1	0.45	7	0.13	31	0.0	058	(	0.131	
Layer	Layer	Sat. Hyd.		Dra	inage	Drain		Leachate	;	Recirc	. to	Subsurface	
#	Туре	Conductivity	/	Len	gth	Slope		Recirc.		Layer		Inflow	
	-	(cm/sec)		(ft)		(%)		(%)		(#)		(ın/yr)	
	1	3.1E-03											
2	1	4.1E-05											
5	1	1.5E-04		505		2							
4	2	3.81E-02		282		2							
5	4	2.0E-13											
0	3	3.0E-08											
0	1	1.0E-00											
0 1	I Larrer	1.0E-03				nhaor - T				tautila			
	Layer	Dinholo Dor	ane Geomembrane In			Instal. Geomembrane			Tree	emissivity			
#	1 ype	(#/acre)	nsity Defects				Placement Quality Transmissivity				<sup>2</sup> /sec)		
5	1	1			101			3			(em		
3	4	1			101		3						

## Table A-4. HELP Model Input Data for Year 300<br/>(ST03.D10).

Input P	arameter	(HELP Model )	Duerv)			Generic Input Parameter Value							
Landfil	1 area =		())			0.26	586 acres	1 411					
Percent	of area v	where runoff is i	oossibl	e =		100	%						
Do you	want to	specify initial m	oisture	e storage	? (Y/N)	Y							
Amoun	t of wate	r or snow on su	face =	0		0 in	ches						
CN Inp	ut Param	eter (HELP Mo	del Ou	erv)		CN	Input Para	amet	er Value				
Slope =	=	χ				2 %							
Slope le	ength =					585 ft							
Soil Te	xture =					4 (HELP model default soil texture)							
Vegetat	tion =					4 (i.e., a good stand of grass)							
HELP I	Model Co	omputed Curve	Numbe	r = 46.2		• · · · · · · · · · · · · · · · ·							
Layer			ber	Layer Type									
Topsoil	l		1				1 (vertic	al pe	ercolatio	n laye	er)		
Upper l	Backfill		2				1 (vertic	al pe	ercolatio	n laye	er)		
Erosion	n Barrier		3				1 (vertic	al pe	ercolatio	on laye	er)		
Lateral	Drainage	e Layer	4				2 (latera	l dra	inage la	yer)			
HDPE	Geomem	brane & GCL	5				4 (geom	emb	rane line	er)			
Founda	tion Laye	er (1E-06)	6				1 (vertical percolation layer)						
Founda	tion Laye	er (1E-03)	7			1 (vertical percolation			on laye	1 layer)			
Layer	Layer	Layer	Soil	To	tal	Fiel	Field Wilting		ilting	Ι	nitial		
#	Туре	Thickness	Textu	ire Poi	osity	Cap	acity	Po	int	Ν	Moisture <sup>2</sup>		
		(in)	No.	(Ve	ol/Vol)	(Vo	l/Vol)	(V	ol/Vol)	(	Vol/Vol)		
1	1	5.85		0.3	96	0.10	)9	0.0	)47	C	0.109		
2	1	30		0.3	5	0.252 0.181			0	0.252			
3	1	12		0.1	5	0.1 0.0		$\frac{.07}{.027}$ 0		).1			
4	2	12		0.4	13	0.056		0.027		C	0.056		
5	4	0.26							0.1				
6	1	12		0.3	5	0.25	52	0.1	81	0	0.252		
7	l	72		. 0.4	57	0.13	<u>51</u>	0.0	<u>)58</u>	0	0.131		
Layer	Layer	Sat. Hyd.	Dr	ainage	Drain		Leachate	;	Recirc	. to	Subsurface		
#	Туре	Conductivity	Le	ngth	Slope		Recirc.		Layer		Inflow		
1	1	(cm/sec)	(ft	)	(%)		(%)		(#)		(in/yr)		
1	1	3.1E-03											
2	1	4.1E-05											
3	1	1.3E-04	50	-	2								
4	2	3.41E-02	38	5	2								
5	4	0./E-13											
7	1	1.0E-00											
/ Lover	Lover	Geomembran		George	mbrona	stal	Gaomar	hron	10	Gast	tavtila		
Hayer	Type	Dinhole Densi	ə tv	e Geomembrane In			Placemer	nt O		Tron	emissivity		
#	Type	(#/acre)	i y	(#/acre	5 )		riacemen	m Q	uanty	$(cm^2)$	2/sec)		
5	4	1		141	/	3				1500			

# Table A-5. HELP Model Input Data for Year 380(ST05.D10).

Innut P	arameter		Generic Input Parameter Value											
I andfil	$1 \operatorname{area} =$	(IILLI Model)	Query)				0.26	86 acres	1 ui		aiue			
Percent	f area v	where runoff is a	ossible	e =			100	%						
	want to	specify initial m	nisture	e stora	oe?	$(\mathbf{Y}/\mathbf{N})$	Y	/0						
Amoun	t of wate	r or snow on su	rface =	. 50010	.50. (	(1/1()	0 in	ches						
CN Inp	ut Param	eter (HELP Mo	del Ou	erv)			CN	Input Para	amet	er Value				
Slope =	=		aer Qu	<u>er</u> j)			2 %	input i uit		ion variat				
Slope l	enøth =						585 ft							
Soil Te	xture =						4 (HFLP model default soil texture)							
Vegeta	tion =						4 (i.e., a good stand of grass)							
HELP	Model Co	omputed Curve	Numbe	r = 46	5.2									
Layer	Layer Number							Laver Type						
Topsoi	1		1				1 (vertic	al p	ercolatic	on lave	er)			
Upper ]	Backfill		2					1 (vertic	al p	ercolatio	n laye	er)		
Erosior	n Barrier		3					1 (vertic	al p	ercolatio	on laye	er)		
Lateral	Drainage	e Layer	4					2 (latera	l dra	ainage la	yer)	2		
HDPE	Geomem	brane & GCL	5					4 (geom	emb	orane line	er)			
Founda	tion Lay	er (1E-06)	6					1 (vertic	al p	ercolatio	on laye	er)		
Founda	tion Lay	er (1E-03)	7				1 (vertical percolation layer)					er)		
Layer	Layer	Layer	Soil		Total	l	Fiel	d	W	ilting	I	nitial		
#	Туре	Thickness	Textu	Texture Porosity				acity	Pc	oint	1	Moisture <sup>2</sup>		
		(in)	No.	(	(Vol/	/Vol)	(Vo	l/Vol)	(V	ol/Vol)	(	(Vol/Vol)		
1	1	5.84		(	0.396	5	0.10	19	0.0	047	(	0.109		
2	1	30		(	0.35		0.25	252 0.181			(	).252		
3	1	12		(	0.15		0.1 0.07		07	(	).1			
4	2	12		(	0.412	2	0.06		0.03		(	0.06		
5	4	0.26												
6	1	12		(	0.35		0.25	52	0.	181	(	0.252		
7	1	72		(	0.457	7	0.13	1	0.0	058	(	0.131		
Layer	Layer	Sat. Hyd.	Dr	ainage	e	Drain		Leachate	;	Recirc	. to	Subsurface		
#	Туре	Conductivity	Lei	ngth		Slope		Recirc.		Layer		Inflow		
		(cm/sec)	(ft)	)		(%)		(%)		(#)		(ın/yr)		
1	1	3.1E-03												
2	1	4.1E-05												
3	1	1.3E-04		_		•								
4	2	2.98E-02	58:	5		2								
5	4	8.7E-13												
6	1	1.0E-06												
7	l	1.0E-03		G		1 7	. 1		1		0			
Layer	Layer	Geomembran	e	Geo	men	ibrane In	stal.	Geomem	ibrai	ne	Geo	textile		
#	Type	Pinhole Densi	ty	Def	ects		Placement Quality Transmissi			nsmissivity				
-	4	(#/acre)		(#/a	cre)			2			(cm	/sec)		
10	4	11		479				3						

## Table A-6. HELP Model Input Data for Year 480(ST06.D10).

Input P	nnut Parameter (HELP Model Query)							Generic Input Parameter Value						
Landfil	$1 \operatorname{area} =$		Query)				0.26	86 acres	1 41	unieter (	urue			
Percent	t of area y	where runoff is i	oossibl	e =			100	%						
Do you	want to	specify initial m	oisture	e stora	age?	(Y/N)	Y	, .						
Amoun	t of wate	r or snow on su	rface =		- 6	()	0 in	ches						
CN Inp	ut Param	eter (HELP Mo	del Ou	erv)			CN	Input Para	amet	er Value				
Slope =	=	(	<u> </u>	)			2 %				-			
Slope l	ength =						585 ft							
Soil Te	xture =						4 (HELP model default soil texture)							
Vegeta	tion =						4 (i.e., a good stand of grass)							
HELP	Model Co	omputed Curve	Numbe	er = 4	6.2									
Layer	Layer Number						Layer Type							
Topsoil	1		1						al p	ercolatio	n lay	er)		
Upper 1	Backfill		2					1 (vertic	al p	ercolatio	n lay	er)		
Erosior	n Barrier		3					1 (vertic	al p	ercolatio	n lay	er)		
Lateral	Drainage	e Layer	4					2 (latera	l dra	inage la	yer)			
HDPE	Geomem	brane & GCL	5					4 (geom	emb	rane line	er)			
Founda	tion Lay	er (1E-06)	6					1 (vertical percolation layer)						
Founda	tion Lay	er (1E-03)	7				1 (vertical percolation			n layer)				
Layer	Layer	Layer	Soil		Total	l	Fiel	d	W	lting Ir		Initial		
#	Туре	Thickness	Textu	Texture Porosity				acity	Po	int	1	Moisture <sup>2</sup>		
		(in)	No.		(Vol/	/Vol)	(Vo	l/Vol)	(V	ol/Vol)	(	(Vol/Vol)		
1	1	5.82			0.396	5	0.10	19	0.0	)47	(	0.109		
2	1	30			0.35		0.25	52	0.	181	(	0.252		
3	1	12			0.15		0.1		0.07		(	0.1		
4	2	12			0.409	)	0.067		0.036		(	0.067		
5	4	0.26												
6	1	12			0.35	-	0.25	2	0.	181	(	0.252		
7	1	72			0.457	/	0.13	<u> </u>	0.0	158	(	0.131		
Layer	Layer	Sat. Hyd.	Dr	aınag	ge	Drain		Leachate		Recirc	. to	Subsurface		
#	Туре	Conductivity	Le	ngth		Slope		Recirc.		Layer		Inflow		
1	1	(cm/sec)	(π)	)		(%)		(%)		(#)		(in/yr)		
1	1	3.1E-03												
2	1	4.1E-05												
3	1	1.3E-04	50	~		2								
4	2	2.33E-02	58:	5		2								
5	4	8./E-13												
0	1	1.0E-00												
/	I I	1.0E-03		C		.1	- 4 - 1	C	1		C	44:1-		
	Layer	Dinhala Dara	<del>.</del>		omen	iorane in	stal.	Discoment	iorai		Geotextile			
#	1 ype	(#/acre)	ιy		iects			riacemei	nt Q	uanty	1 rat	$\frac{15111551V11y}{2}$		
5	4	1		(#/8	1010) 15			3			(cm	/500)		
5	4	1		111	5		3							

# Table A-7. HELP Model Input Data for Year 660(ST07.D10).

Innut P	arameter		Gen	eric Input	Par	ameter V	/alue							
I andfil	$1 \operatorname{area} =$	(IILLI Model)	Query)				0.26	586 acres	1 ui		arue			
Percent	of area	where runoff is a	ossibl	e =			100	%						
Do you	want to	specify initial m	oisture	e stora	ge?	(Y/N)	Y	/0						
Amoun	t of wate	r or snow on su	rface =	, stora	50.	(1/1()	0 in	ches						
CN Inp	ut Param	eter (HELP Mo	del Ou	erv)			CN Input Parameter Value							
Slope =	=		<u>uei Qu</u>	<u>(1)</u>										
Slope l	enøth =						585 ft							
Soil Te	xture =						4 (HELP model default soil texture)							
Vegeta	Vegetation =							e., a good	star	nd of gra	ss)			
HELP	Iodel Computed Curve Number = 46.2													
Layer Layer Number							Laver Type							
Topsoi	soil 1							1 (vertic	al p	ercolatic	on lave	er)		
Upper ]	Backfill		2					1 (vertic	al p	ercolatio	n laye	er)		
Erosior	n Barrier		3					1 (vertic	al p	ercolatio	n laye	er)		
Lateral	Drainage	e Layer	4					2 (latera	l dra	ainage la	yer)			
HDPE	Geomem	brane & GCL	5					4 (geom	emb	orane line	er)			
Founda	tion Lay	er (1E-06)	6					1 (vertical percolation layer)						
Founda	tion Lay	er (1E-03)	7					1 (vertic	al p	ercolatic	on laye	er)		
Layer	Layer	Layer	Soil	1	Fotal	l	Fiel	d	W	ilting	I	nitial		
#	Туре	Thickness	Textu	Texture Porosity				acity	Pc	oint	N	Aoisture <sup>2</sup>		
		(in)	No.	Jo. (Vol/Vol)			(Vo	l/Vol)	(V	ol/Vol)	(	Vol/Vol)		
1	1	5.76		(	).396	5	0.10	09 0.047			0	.109		
2	1	30		(	).35		0.25	0.252 0.181			0	.252		
3	1	12		(	).15		0.1 0.07			07	0	.1		
4	2	12		(	).403	3	0.084		0.049		0	.084		
5	4	0.26												
6	1	12		(	).35	_	0.25	52	0.	181	0	.252		
7	1	72		(	).457	7	0.13	51	0.0	058	0	.131		
Layer	Layer	Sat. Hyd.	Dr	ainage	e	Drain		Leachate	•	Recirc	. to	Subsurface		
#	Туре	Conductivity	Le	ngth		Slope		Recirc.		Layer		Inflow		
	_	(cm/sec)	(ft)	)		(%)		(%)		(#)		(ın/yr)		
1	1	3.1E-03												
2	1	4.1E-05												
3	1	1.3E-04	50	~		2								
4	2	1.28E-02	58:	5		2								
5	4	8./E-13												
0	1	1.0E-00												
/	1 1	1.0E-03		C		.1	-4-1	C	.1		C.			
	Layer	Geomembrane Dimbola Da	e +	Geo D-f	men	iorane In	stal.	Discourse	ibrai	ne nalita	Geot	extile		
#	1 ype	(#/agra)	ιy					Placeme	m Q	uanty	1 ran	sinissivity		
5	4	(#/acre)		(#/a	ore)			2			(cm <sup>2</sup>	/sec)		
3	4	1		200	9		3							

# Table A-8. HELP Model Input Data for Year 1,100(ST08.D10).

Appendix B. HYDRUS-1D Input Parameters

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Main Processes	×	Geom	netry Ir	nformati	on				×
Heading		-l anv	ath Lloit	ha					
Operational Soil Cover for Slit Trench Unit - Single 4	4-foot Layer	reni	yan <u>o</u> nia			Number of Soil Mat	erials	OK.	
Circles .	-	С	mm		_				
Simulate	verse Solution ?	(	cm	1		Number of <u>L</u> ayers f	or Mass Balances	Cance	
		C	m			Decline from ⊻ertic	al Axes	Previous	
Snow Hydrology						(=1: vertical; =0: ho	orizontal)	Nevt	
Solute Transport					22	Depth of the Soil P	rofile [cm]	<u></u>	·
Standard Solute Transport					22		ionie (cin)	<u>H</u> elp	
C Major Ion Chemistry									
C HP1 (PHREEQC)	OK	-	Time I	nformat	ion				×
Heat Iransport	Cancel		nine i	mormat					~
Root Water Uptake	blaub.		Time	Units —	1 E Time D	)iscretization		-	
Root Growth	<u>IN</u> ext		<u> </u>	econds	Initial T	ime [year]:	0	UK	
CO2 Transport	<u>H</u> elp		○ <u>▶</u>	<u>/</u> inutes	<u> </u>	ime [year]:	100	Cancel	
			ОН	lours	Initial T	ime Step [year]:	2.73973e-006	Previous .	
		-	C D	)aus	Minimu	m Time Step (vear):	2.73973e-008	Next	
oil Hydraulic Model				<u>/</u> uyo	kil suissi	im Time Step (vesi)	1		
Hydraulic Model			<u> Y</u>	ears	Maximu	an nine step lyear)	• J'		
Single Porosity Models			- Time	-Variable B	Boundary (	Conditions			
van <u>G</u> enuchten - Mualem			<b>▼</b> T	ime-⊻ariat	ole Bounda	ary Conditions			
With Air-Entry Value of -2 cm			1	00	Number o	f Time-Variable Bou	indary Records (e.g.	Precipitation)	
C Modified van Genuchten					the serve	and of P.C.	himner		
C Kosugi (log-pormal)		-		nepeat	une same	set of bit records h	umes:		
Dual Development Dual Development Studies				Daily Va	ariations of	Transpiration Durin	ng Day <u>G</u> enerated by	HYDRUS	
Dual-Porosity/Dual-Permeability Models	Musles)			Sinusoi	dal Variatio	ons of Pre <u>c</u> ipitation	Generated by HYDR	US	
C Dual-porosity (Durner, dual van Genuchten -	• Mualemj		⊢ ⊢ M	1eteorolog	jical Data-				
<ul> <li>Dual-porosity (mobile-immobile, water c. mas:</li> <li>Dual-porosity (mobile-immobile, bead mass tr.</li> </ul>	ansfer)	4		Meteoro	ological Da	ita			
Models below are recommended only for evo	erienced users			100	Numbe	r of Meteorological	<u>R</u> ecords (e.g., Radia	ation)	
C. Dual-permeability (Kinematic wave equation)				Peni	man-Month	neith Eguation			
Dual-permeability (Rinematic wave equation)     Dual-permeability (Renke and van Genuchte	n 1992)			C Harg	jreaves Fo	rmula			
C Look up Tables	(, 1000)			C Ener	gy <u>B</u> alanc	e Boundary Conditi	or		
C Look-up l'ables				🔽 Daily	Variation:	s of Meteo Data Du	ring Day Generated	by HYDRUS	
Hysteresis				Root W	ater and	Solute Uptake M	lodel		X
No nysteresis									
<ul> <li>Hysteresis in retention curve and conductivitu.</li> </ul>				⊢ Hoot V	Vater Uptał er Uptake I	ke Model Beduction Model —			
C Hysteresis in retention curve (no pumping, Bob	Lenhard)			( E	eddes				
C Initially drving curve	,			0.9	<u>Shape</u>			Cancel	
C Initially wetting curve				Solu	ute Stress M	lodel			
				( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( )	N <u>o</u> Solute S	itress		<u>P</u> revious	
Vater Flow Boundary Conditions		$\times$		0/	Additive Mo	odel			
Upper Boundary Condition					dultiplicativ	e Model		<u>N</u> ext	
C Constant Water Content	OK				C <u>T</u> hresh C SiShan	old Model		Help	-1
C Constant Flux	Connel					2		<u> </u>	
C Atmospheric PC with Surface Laver	Lancei			1	!	C <u>r</u> itical Stress Index I	ior Water Uptake		
Autospheric DC with Surface Day Off	<u>P</u> revious			- Root 9	Solute Upta	ke Model			
Atmospheric BC with Surrace <u>H</u> un Urr	blbl						Active Solute Upt	ake	
Variable Pressure Head							Solute with	Active Uptake	
C Varia <u>b</u> le Pressure Head/Flux	<u>H</u> elp						0 Potential S	olute <u>U</u> ptake Rate	
Triggered Irrigation		- V	Vater F	low Para	meters				
- Lower Boundary Condition	al Condition		Mat	Or [.]	0.1	Alpha [1/cm]	n [-]	Ks [cm/year]	1
C Constant Water Content	n Press <u>u</u> re Heads		1	0.04	17 0 3	96 0.07	5 1.89	3153	6
C Constant Flux	n <u>W</u> ater Contents		-	0.0			- 1.05	5155	-
Variable Pressure Head									
C Variable Flu <u>x</u>									
Free Drainage									
O Deep Drainage									
○ <u>S</u> eepage Face; h =									
<ul> <li>Horizontal Drains</li> </ul>									
			<u>S</u> oil Cat	alog 🛛		▼ N <u>e</u>	ural Network Prediction	<u>I</u> emperatur	e Depe
								1	
				OK		Cancel Pr	evious <u>N</u>	ext	<u>H</u> elp



Root Gro	wth Param	eters			×	7		N	Aeter	prological P	arameters	:				×
	and ratali				^				- Badi	iation	arameters	,				
Root D	epth Specifie	d — Ca				1			( F	Potential Radi	ation O S	olar Radiat	ion O N	let Radiation	[[	OK
	n Time-Valiau na a Tablo	ile boundary co	Jrialaoris		UK				Geog	graphical and	Meteorologia	al Paramete	ers			
		( C	L		Cancel				33.2	2 Latit	ude (deg, N+	•,S•) 120	∆lti	tude (m)		Cancel
10	INUMDe	r or Growth Dai			Previous				Angs	trom values (:	short wave ra	adiation):			. <u>P</u> re	evious
	lirow	th Data							0.25	Ang	strom value a	a  0.5	An	gstrom value		Jevt
🖲 Usi	ing a Logistic	<u>G</u> rowth Functio	n		<u>N</u> ext					diness effect (	on long wave	e radiation (s	et 0 if input	transm. coeff	t.):	<u>10x(</u>
Ro	ot Growth Fac	ctor			Help				Clour	diness Factor	from Solar B	adiation:	DI			Help
	From Given L	/ata % Growing copo			<u>1</u> 04P				1.35	ac ac	nom Solar H	-0.35	i bo		- Cloudin	ess
	- Counter Do	s alovning seas	on	Root Wate	r Uptake Pa	rameters	×		Emis	sivity effect or	n long wave	radiation:			Suns	hine
- HO	ot Growth Da	l Daah Caawila	Tim = [		- optane re				0.34	al		-0.13	9 Ы		C Clou	diness
0.1	Inio		nme (year)	Feddes' P	arameters		700	1	Mea	surement Heig	ghts:				C Iran	smission c. Rediction
0.8	H <u>a</u> r	vest 1 me [year	1	P <u>0</u> [cm]	0		UN		200	Win	d speed (cm)	200	Ter	mpe <u>r</u> ature (cr	n) 🕒 🕬	Traulation
0.0	1 Initi	al <u>R</u> ooting Dept	th [cm]	POpt [cm]	-1	- C	ancel		🖲 Re	ative Humidit	yor 🔿 Vap	or Pressure	specified [	Leaf Area Ir	ndex	
90	<u>M</u> a>	kimum Rooting [	Depth [cm]	P2H form1	200		· · ·	l l r	- Crop	Data			·	í <u>G</u> iven	u : u er	10
0.3	<u> </u>	e - Root Data (J	year]		-300	<u>P</u> re	vious		0	No Crop	15 Cr	op Height [o	:m]	C From Cr	iop Height, Uli iop Height, Alf	pped Grass
20	Dep	th - Root Data	[cm]	P2 <u>L</u> [cm]	·1000	N	lext.			Constant	0.23 AI	bedo		C From Si	urface Fraction	n
1	Tim	e-Period [uear]		P <u>3</u> [cm]	-16000				0	- Tables	3.5	VSurface F	raction	0.462 D	adiation Eutin	otion
		en enoù Mearl		r2H [cm/ve	arl 182.5	-	<u>H</u> elp		0	Daily	0	not Depth Ic	ml	JU.463 h	adiation Extin	ction
				1							(O) 10	oor o epin (c	ang [	Interception		
				IZL [cm/ye	arj  36.5				10	Numbe	r of Growth D	) ata		I Intercep	tion	
				Database			-	1		Growt	h Data			1.5 Ir	nterception Co	onstant [mm]
					1			<u> </u>								
Soil Profile	e Summary						×	Time	Variab	ole Boundary	Conditions					×
	z [cm]	theta Ro	ot [1/cm	Axz	Bxz D	xz N	lat 🔺			Time			Precip.		hCritA	
1	0	0.109	0	1	1	1	1			[year]	]	[c	m/year]		[cm]	_
2	1.22	0.109	0	1	1	1	1	1			1		10	1.778		1000000
4	3.66	0.109	0	1	1	1	1	2			2		14	5.136		1000000
5	4.88	0.109	0	1	1	1	1	3			3		13	3.706		1000000
6	6.1	0.109	0	1	1	1	1	4			4		12	1.615		1000000
7	7.32	0.109	0	1	1	1	1	5			5		12	8.448		1000000
8	8.54	0.109	0	1	1	1	1	6			6		10	7.391		1000000
9 10	9.70	0.109	0	1	1	1	1	7			7		9	9.949		1000000
11	12.2	0.109	0	1	1	1	1	8	_		8		12	5.628		1000000
12	13.42	0.109	0	1	1	1	1	9	_		9		12	3.419		1000000
13	14.64	0.109	0	1	1	1	1	10	_		10		13	7.084		1000000
14	15.86	0.109	0	1	1	1	1	11	-		11		1	46.38		1000000
15	17.08	0.109	0	1	1	1	1	12	-		12		11	8.643		1000000
<b>10</b>	18.3	0.109	U	1	1	1	Ì	1/			13		9/	.9932 5 205		1000000
[[		Cancel	Pres	ioue	Neut	1 4	elo I		пк	Cancel	Previous	Next	Help	Add Line	Delete Line	Default Time
<u> </u>		Cancer			Next		eip					<u></u>	<u> </u>			
veteorol	logical Con	ditions						×								
	Time	No Inform	T_max	T_min	Humidity	Wind	Sunshine	e 🔺	]							
	[year]	NO INOMI.	[°C]	[°C]	[%]	[km/d]	[hr]		1							
1	1	0	30	12	52	350	273	38								
2	2	0	30	12	52	350	273	38								
3	3	0	30	12	52	350	273	38								
4	4	0	30	12	52	350	273	38								
5	5	0	30	12	52	350	273	38								
6	6	0	30	12	52	350	273	38								
/	7	0	30	12	52	350	273	38								
8	8	0	30	12	52	350	2/3	38								
9	9	0	30	12	52	350	2/3	38								
10	10	0	30	12	52	350	2/3	20								
12	12	0	30	12	52	300	2/3	38								
13	12	0	30	12	52	350	273	38								
1/	1/	0	20	12	52	250	2/3	20								
OK	Canc	el <u>P</u> revious	<u>N</u> ext	<u>H</u> elp	Add Line	Delete Lir	ne Default	<u>T</u> ime								

\* The Soil Profile Summary, Time Variable Boundary Conditions, and Meteorological Conditions screen captures show only a small portion of the total input dataset due to their large size.



	^	Geor	metry Informat	tion		×
agling:		Ler	ngth <u>U</u> nits			
perational Soil Cover for Slit Trench Unit -	Single 4-foot Layer	0	mm	1 Number of Soil <u>M</u> ateri	als	OK
- Simulate	Inverse Solution 2			1 Number of Layers for	Mass Balances	Cancel
✓ <u>W</u> ater Flow	I Inverse solution ?		Cm I			Previous
□ Vapor Flow			m	1 (=1: vertical; =0: horiz	axes :ontal)	
Solute Transport			l r	100 Deeth state Call Deet	I- ()	<u>N</u> ext
Standard Solute Transport				122 Depth of the Soll Prof	ie (cm)	<u>H</u> elp
C Major Ion Chemistry						
C HP1 (PHREEQC)	UK		Time Informa	tion		×
Heat Iransport	Cancel					
Boot Water Uptake	Next		Time Units	Time Discretization		ΟΚ
Root Growth			C Seconds	Initial Time [day]:	0	Canaal
CD2 Transport			C <u>M</u> inutes	Einal Time [day]:	36524	Deview
			C Hours	Ini <u>t</u> ial Time Step [day]:	0.001	Previous
il Hydraulic Model			I ● Days	Minim <u>u</u> m Time Step [day]:	1e-005	<u>N</u> ext
lydraulic Model			C Years	M <u>a</u> ximum Time Step [day]:	0.01	<u>H</u> elp
Single Porosity Models			🕞 Time-Variable	Boundary Conditions		
van <u>G</u> enuchten - Mualem			Time-⊻aria	ble Boundary Conditions		
With Air-Entry Value of -2 cm		_	36524	Number of Time-Variable Bound	dary Records (e.a. Pr	ecipitation1
O Brooks-Corey			E Benea	t the same set of BC records a tir	nes:	,,
C Kosugi (log-normal)				Cariations of Transmission During	Day Gaparated by US	
-Dual-Porosity/Dual-Permeability Models -				idal Variations of Presidiation During	oray <u>cr</u> enerated by H1 merated by H∨DD110	Dhus
C Dual-porosity (Durner, dual van Genu	uchten - Mualem)		j Sinusu	-idal Valiations of Fre <u>ci</u> pitation de	neialeu by hi bhus	
C Dual-porosity (mobile-immobile, water	c. mass transfer)		Meteoroio	gicai Data rological Data		
C Dual-porosity (mobile-immobile, head	mass transfer)		36524	Number of Meteorological Pr	ecordo (e.a. Redistion	a)
== Models below are recommended only	for experienced users ==		@ Per	man.Montheith Equation	scoras (e.g., madiador	ŋ
C Dual-permeability (Kinematic wave ed	quation) mustates 1993)		C Har	roreaves Formula		
C Look up Tables	nuchten, 1993j		C Ene	ergy <u>B</u> alance Boundary Condition		
			🔽 Dai	ly Variations of Meteo Data Durin	g Day Generated by I	HYDRUS
No husteresis			Root V	Vater and Solute Uptake Mo	del	>
Hysteresis in retention curve			- Boot	Water Untake Model		
Hysteresis in retention curve and condu	uctivity		₩a	ater Uptake Reduction Model		OK OK
Hysteresis in retention curve (no pumping)	ng, Bob Lenhard)			<u>F</u> eddes		
C Initially drying curve				<u>o</u> -onape lute Stress Model		Cancel
C Initially wetting curve			_    @	No Solute Stress		Previous
ater Flow Boundary Conditions		×	C	Additive Model		
Hoper Boundary Condition			C	Multiplicative Model		<u>N</u> ext
C Constant Water Content	OK			C Threshold Model		Halp
	Coursel			U p-pnape		
Atmospheric BC with Surface Laver	Lancer		1	Critical Stress Index for	Water Uptake	
Atmospheric BC with Surface Bun C	ff Previous	\$	Root	Solute Uptake Model		
<ul> <li>Variable Pressure Head</li> </ul>	Next				Active Solute Uptake	; tius Uptaka
○ Variable Pressure Head/Flux					Potential Solut	ta Untaka Rata
Triggered Irrigation	<u>H</u> elp		unter El E	Ju	i otentiai pulu	to <u>optake</u> i fate
		V	water FIOW Parar	neters		
Lower Boundary Condition	Initial Condition		Mat Qr [-]	Qs [-] Alpha [1/cm]	n [-] K	(s [cm/day] I
Constant Water Content	In Water Contents		1 0.04	7 0.396 0.075	1.89	86.4
Constant Flux						
○ Variable Pressure Head						
⊂ <u>V</u> ariable Pressure Head ⊂ Variable Flu <u>x</u>						
C ⊻ariable Pressure Head C Variable Flu <u>x</u> Free Drainage						
C Variable Pressure Head C Variable Flux I Free Drainage Deep Drainage						
C <u>V</u> ariable Pressure Head C Variable Flu <u>x</u> I Free Drainage C <u>D</u> eep Drainage C <u>S</u> eepage Face; h =						
C <u>V</u> ariable Pressure Head C Variable Flu <u>x</u> In Free Drainage C <u>D</u> eep Drainage C <u>S</u> eepage Face; h = C Horjzontal Drains			Soil Catalog	N	Notwork Production	Tomperature David





\* The Soil Profile Summary, Time Variable Boundary Conditions (ATMOSPH – Master.IN), and Meteorological Conditions (METEO.IN) screen captures show only a small portion of the total input dataset due to their large size.

## Case 3-1a/b – Soil Profile Summary

z[cm]	theta	Root[1/cm]	Axz	Bxz	Dxz	Mat	Laver
0	0.109	0	1	1	1	1	1
1.22	0.109	0	1	1	1	1	1
2 44	0.109	Õ	1	1	1	1	1
3.66	0.109	0	1	1	1	1	1
1.88	0.109	0	1	1	1	1	1
4.00	0.109	0	1	1	1	1	1
0.1	0.109	0	1	1	1	1	1
1.52	0.109	0	1	1	1	1	1
8.34	0.109	0	1	1	1	1	1
9.76	0.109	0	1	1	1	1	1
10.98	0.109	0	l	l	l	l	l
12.2	0.109	0	1	1	1	1	1
13.42	0.109	0	1	1	1	1	1
14.64	0.109	0	1	1	1	1	1
15.86	0.109	0	1	1	1	1	1
17.08	0.109	0	1	1	1	1	1
18.3	0.109	0	1	1	1	1	1
19.52	0.109	0	1	1	1	1	1
20.74	0.109	0	1	1	1	1	1
21.96	0 1 0 9	Õ	1	1	1	1	1
23.18	0.109	ů 0	1	1	1	1	1
23.10	0.109	0	1	1	1	1	1
24.4	0.109	0	1	1	1	1	1
25.02	0.109	0	1	1	1	1	1
20.84	0.109	0	1	1	1	1	1
28.06	0.109	0	1	1	1	1	1
29.28	0.109	0	l	I	l	I	1
30.5	0.109	0	1	1	1	1	1
31.72	0.109	0	1	1	1	1	1
32.94	0.109	0	1	1	1	1	1
34.16	0.109	0	1	1	1	1	1
35.38	0.109	0	1	1	1	1	1
36.6	0.109	0	1	1	1	1	1
37.82	0.109	0	1	1	1	1	1
39.04	0 1 0 9	0	1	1	1	1	1
40.26	0 1 0 9	Ő	1	1	1	1	1
41.48	0.109	0 0	1	1	1	1	1
41.40	0.109	0	1	1	1	1	1
42.7	0.109	0	1	1	1	1	1
45.92	0.109	0	1	1	1	1	1
45.14	0.109	0	1	1	1	1	1
46.36	0.109	0	1	l	1	l	l
47.58	0.109	0	1	I	l	I	I
48.8	0.109	0	1	1	1	1	1
50.02	0.109	0	1	1	1	1	1
51.24	0.109	0	1	1	1	1	1
52.46	0.109	0	1	1	1	1	1
53.68	0.109	0	1	1	1	1	1
54.9	0.109	0	1	1	1	1	1
56.12	0.109	0	1	1	1	1	1
57 34	0 109	Õ	1	1	1	1	1
58 56	0 100	0 0	1	1	1	1	1
50.50	0.109	0	1	1	1	1	1
57.70 61	0.109	0	1	1	1	1	1
(2.22	0.109	0	1	1	1	1	1
02.22	0.109	U	1	1	1	1	1
63.44	0.109	0	1	1	1	1	1

z[cm]	theta	Root[1/cm]	Axz	Bxz	Dxz	Mat	Layer
64.66	0.109	0	1	1	1	1	1
65.88	0.109	0	1	1	1	1	1
67.1	0.109	0	1	1	1	1	1
68.32	0.109	0	1	1	1	1	1
69.54	0.109	0	1	1	1	1	1
70.76	0.109	0	1	1	1	1	1
71.98	0.109	0	1	1	1	1	1
73.2	0.109	0	1	1	1	1	1
74.42	0.109	0	1	1	1	1	1
75.64	0.109	0	1	1	1	1	1
76.86	0.109	0	1	1	1	1	1
78.08	0.109	0	1	1	1	1	1
79.3	0.109	0	1	1	1	1	1
80.52	0.109	0	1	1	1	1	1
81.74	0.109	0	1	1	1	1	1
82.96	0.109	0	1	1	1	1	1
84.18	0.109	0	1	1	1	1	1
85.4	0.109	0	1	1	1	1	1
86.62	0.109	0	1	1	1	1	1
87.84	0.109	0	1	1	1	1	1
89.06	0.109	Ő	1	1	1	1	1
90.28	0.109	Ő	1	1	1	1	1
91.5	0.109	Ő	1	1	1	1	1
92.72	0 109	Ő	1	1	1	1	1
93.94	0.109	Ő	1	1	1	1	1
95.16	0 109	Ő	1	1	1	1	1
96.38	0 109	Ő	1	1	1	1	1
97.6	0 109	Ő	1	1	1	1	1
98.82	0.109	Ő	1	1	1	1	1
100.04	0.109	Ő	1	1	1	1	1
101.26	0.109	Ő	1	1	1	1	1
102.48	0.109	Ő	1	1	1	1	1
102.40	0.109	0	1	1	1	1	1
104.92	0.109	0	1	1	1	1	1
104.92	0.109	0	1	1	1	1	1
107.36	0.109	0	1	1	1	1	1
107.50	0.109	0	1	1	1	1	1
100.50	0.109	0	1	1	1	1	1
111.02	0.109	0	1	1	1	1	1
112.24	0.109	0	1	1	1	1	1
112.24	0.109	0	1	1	1	1	1
117.40	0.109	0	1	1	1	1	1
114.00	0.109	0	1	1	1	1	1
117.7	0.109	0	1	1	1	1	1
118 3/	0.107	0	1	1	1	1	1
110.54	0.109	0	1	1	1	1	1
120.78	0.109	0	1	1	1	1	1
120.70	0.109	0	1	1	1	1	1
144	0.109	U	1	1	1	1	1



Main Processes X	Geometry Information	×
l la dian	- Longth Units	
Heaging:	2 Number of Soil Materials	ОК
- Simulato	O mm	Cancel
✓ Water Flow	Cm IS Number of Eavers for Mass balances	
☐ ⊻apor Flow	O m Decline from ⊻ertical Axes	Previous
Snow Hydrology	(=1. venical, =0. holizonial)	<u>N</u> ext
Solute Transport	122 Depth of the Soil Profile [cm]	Help
Standard Solute Fransport		
C HP1 (PHREEQC)		
Heat Transport Cancel	Time Information	X
Boot Water Uptake	Time Units	
Root Growth	C Seconds Initial Time [day]: 0	<u>     UK          </u>
□ <u>C</u> O2 Transport <u>H</u> elp	C Minutes Einal Time (day): 36524	Cancel
	C Hours Initial Time Step (day): 0.001	Previous
Soil Hydraulic Model	Days Minimum Time Step [day]: 1e-005	<u>N</u> ext
Ludes die Medel	C Years Maximum Time Step (day): 0.01	<u>H</u> elp
Single Porosity Models	OK	
van <u>G</u> enuchten - Mualem		
☐ With Air-Entry Value of -2 cm	Cancel 36524 Number of Time-Variable Boundary Becords (e.g.	- Precipitation)
C Modified van Genuchten	Braviews Respect the same set of PC records a times	
C Kosugi (log-normal)		
Dual-Porosity/Dual-Permeability Models	Next	
C Dual-porosity (Durner, dual van Genuchten - Mualem)	Help Meteorological Data	nos
C Dual-porogity (mobile-immobile, water c. mass transfer)	Meteorological Data	
<ul> <li>Dual-porosity (mobile-immobile, head mass transfer)</li> </ul>	36524 Number of Meteorological Becords (e.g., Bac	fiation)
== Models below are recommended only for experienced users ==	Penman-Montheith Equation	action (
O Dual-permeability (Kinematic wave <u>equation</u> )	C Hargreaves Formula	
C Lookup Tables	C Energy Balance Boundary Condition	
	Daily Variations of Meteo Data During Day Generated	d by HYDRUS
No hysteresis		
C Hysteresis in retention curve	Water Flow Boundary Conditions	×
C Hysteresis in retention curve and <u>c</u> onductivity	- Upper Roundary Condition	
C Hysteresis in retention curve (no pumping, Bob Lenhard)	C. Constant ) (stor Contant	OK
C Initially drying curve		
	C Atmospheric BC with Surface Lauer	Cancel
Water Flow Decomptors		Previous
water now Parameters		Next
Mat         Qr [-]         Qs [-]         Aipha [1/Cm]         n [-]         Ks [4           1         0.047         0.396         0.075         1.80	86.4 0.5 C Variable Pressure Head/Flux	Help
2 0.4 0.75 0.005 1.09	0.00432 0.5 Triggered Irrigation	
		ondition
	C Constant Water Content	ressure Heads
	C Constant Flux	/ater Contents
	O Variable Pressure Head	
	O Variable Flux	
	Free Drainage	
Soil Catalog Neural Network Prediction	Imperature Dependence	
TK Cancel Previous Meut	Help   O Seepage Face; h =	
	C Horizontal Drains	



#### <u>Case 3-2a – Institutional Control (K<sub>sat HDPE</sub> = 5.0E-08 cm/sec)</u>

\* The Soil Profile Summary, Time Variable Boundary Conditions (ATMOSPH – Master.IN), and Meteorological Conditions (METEO.IN) screen captures show only a small portion of the total input dataset due to their large size.



Main Processes X	Geometry	nformatio	on		×
Line Jacob		te			
Institutional Control Case			Number of Soil Materials		OK
	C mm				
Simulate	C cm	3	Number of <u>Layers</u> for Mass	Balances	Lancel
I ✓ Water Flow	C m		Decline from Vertical Axes		Previous
Show Hydrology			(=1: vertical; =0: horizontal)	)	Nevt
Solute Transport		12	Depth of the Soil Profile [cm	าไ	
Standard Solute Transport					<u>H</u> elp
C Major Ion Chemistry					
	Time	nformati	on		×
Heat Iransport     Cancel		11.5	The Driver of the		
☐ <u>R</u> oot Water Uptake <u>N</u> ext		Units	I ime Discretization		OK I
Root Growth		econas	Tinual Time (day).	504	Cancel
<u> </u>		<u>A</u> inutes	Final Time (day):	024	Braviaus
	0	1 <u>o</u> urs	Initial Time Step [day]: U.I	001	
Soil Hydraulic Model	• <u>I</u>	<u>)</u> ays	Minimum Time Step [day]: 1e	+005	<u>N</u> ext
- Hydraulic Model	0	<u>(</u> ears	M <u>a</u> ximum Time Step [day]: 0.0	01	<u>H</u> elp
Single Porosity Models	OK Time	-Variable B	oundary Conditions		
van Genuchten - Mualem	· · · · · · · · · · · · · · · · · · ·	ime- <u>V</u> ariabl	e Boundary Conditions		
With <u>Air-Entry Value of -2 cm</u>	Cancel	6524	Number of Time-Variable Boundary R	ecords (e.a., Pred	cipitation)
C Modified van Genuchten	Previous		he same set of BC records n times:	1	,
C Kosugi (log-normal)		7 Dailu Va	intinue of Transmission During Day 6	L' Commente d'hui LIVE	DUC
Dual-Porosity/Dual-Permeability Models	<u>N</u> ext	<ul> <li>Daily val</li> <li>Sipusoid</li> </ul>	al Variations of Precipitation Generat	ad by HYDRUS	nus
O Dual-porosity (Durner, dual van Genuchten - Mualem)		Actoorologi	al Valiations of Fre <u>e</u> ipitation dienerati	ed by III DI103	
C Dual-porosity (mobile-immobile, water c. mass transfer)		Meteorologi Meteorol	logical Data		
<ul> <li>Dual-porosity (mobile-immobile, head mass transfer)</li> </ul>		36524	Number of Meteorological Becord	e (e.a. Badiation)	
== Models below are recommended only for experienced users ==		Penr	an-Montheith Equation	s (c.g., maaladon)	
C Dual-permeability (Kinematic wave <u>e</u> quation)		C Harg	eaves Formula		
O Dual-permeability (Gerke and Van Genuchten, 1993)		C Energ	y <u>B</u> alance Boundary Condition		
		🔽 Daily	Variations of Meteo Data During Day	Generated by H	/DRUS
Hysteresis		-			
C Husteresis in retention curve		Wate	r Flow Boundary Conditions		×
C Hysteresis in retention curve and <u>c</u> onductivity		wate			~
C Hysteresis in retention curve (no pumping, Bob Lenhard)			per Boundary Condition	[ <u>[</u> "	
C Initially drying curve		0	Constant Water Content	<u> </u>	
C Initially wetting curve		0	Constant <u>F</u> lux		Cancel
			Atmospheric BC with Surface Layer Atmospheric BC with Surface Run (	Off	<u>P</u> revious
Water Flow Parameters	×	0	V <u>a</u> riable Pressure Head		<u>N</u> ext
Mat Or [-] Os [-] Alpha [1/cm] n [-] Ks [/	cm/dav] [[-]	0	Varia <u>b</u> le Pressure Head/Flux		Help
1 0.047 0.396 0.075 1.89	86.4 0.5		Triggered Irrigation		<u> </u>
2 0.4 0.75 0.005 1.09	8.64E-005 0.5		ver Boundary Condition	- Initial Conditio	n
			Constant Water Content	C In Pressure	e Heads
		C	Constant Flux	In Water C	ontents
		0	- Variable Pressure Head		
			Variable Flux		
			Free Drainage		
			Deen Drainage		
Soil Catalog Neural Network Prediction	$\underline{I}$ emperature Dependence		Seenage Face: h =		
OK Cancel Previous Next	Help	C	Horizontal Drains		



#### <u>Case 3-2b – Institutional Control ( $K_{sat HDPE} = 1.0E-09 \text{ cm/sec}$ )</u>

\* The Soil Profile Summary, Time Variable Boundary Conditions (ATMOSPH – Master.IN), and Meteorological Conditions (METEO.IN) screen captures show only a small portion of the total input dataset due to their large size.

## Case 3-2a/b – Soil Profile Summary

z[cm]	theta	Root[1/cm]	Axz	Bxz	Dxz	Mat	Layer
0	0.109	0	1	1	1	1	ĩ
0.01	0.109	0	1	1	1	1	1
0.02	0.109	0	1	1	1	1	1
0.03	0.109	0	1	1	1	1	1
0.04	0.109	0	1	1	1	1	1
0.05	0.109	0	1	1	1	1	1
0.06	0.109	Ő	1	1	1	1	1
0.07	0 109	Ő	1	1	1	1	1
0.08	0 109	Ő	1	1	1	1	1
0.09	0 109	Ő	1	1	1	1	1
0.05	0 109	Ő	1	1	1	1	1
0.1001	0.107	Ő	1	1	1	2	2
0.105	0 747	Ő	1	1	1	2	2
0.11	0.747	Ő	1	1	1	2	2
0.115	0.747 0.747	0	1	1	1	2	2
0.113	0.747	0	1	1	1	2	$\frac{2}{2}$
0.12	0.747	0	1	1	1	2	2
0.125	0.747	0	1	1	1	2	2
0.13	0.747	0	1	1	1	2	2
0.135	0.747	0	1	1	1	2	2
0.14	0.747	0	1	1	1	2	2
0.145	0.747	0	1	1	1	2	2
0.15	0.747	0	1	1	1	2	2
0.155	0.747	0	1	1	1	2	2
0.16	0.747	0	1	1	1	2	2
0.165	0.747	0	1	1	1	2	2
0.17	0./4/	0	1	1	1	2	2
0.175	0.747	0	1	l	1	2	2
0.18	0.747	0	1	1	1	2	2
0.185	0.747	0	l	l	l	2	2
0.19	0.747	0	1	1	1	2	2
0.195	0.747	0	1	1	1	2	2
0.2	0.747	0	1	1	1	2	2
0.205	0.747	0	1	1	1	2	2
0.21	0.747	0	1	1	1	2	2
0.215	0.747	0	1	1	1	2	2
0.22	0.747	0	1	1	1	2	2
0.225	0.747	0	1	1	1	2	2
0.23	0.747	0	1	1	1	2	2
0.235	0.747	0	1	1	1	2	2
0.24	0.747	0	1	1	1	2	2
0.245	0.747	0	1	1	1	2	2
0.2524	0.747	0	1	1	1	2	2
0.2525	0.109	0	1	1	1	1	3
0.3	0.109	0	1	1	1	1	3
0.35	0.109	0	1	1	1	1	3
0.4	0.109	0	1	1	1	1	3
0.5	0.109	0	1	1	1	1	3
1	0.109	0	1	1	1	1	3
3	0.109	0	1	1	1	1	3
5	0.109	0	1	1	1	1	3
7	0.109	0	1	1	1	1	3
9	0.109	0	1	1	1	1	3
11	0.109	0	1	1	1	1	3
		-					-

z[cm]	theta	Root[1/cm]	Axz	Bxz	Dxz	Mat	Laver
13	0.109	0	1	1	1	1	š
15	0.109	0	1	1	1	1	3
17	0.109	0	1	1	1	1	3
19	0.109	0	1	1	1	1	3
21	0.109	Ő	1	1	1	1	3
23	0 109	Ő	1	1	1	1	3
25	0.109	Ő	1	1	1	1	3
23	0.109	0	1	1	1	1	3
29	0.109	Ő	1	1	1	1	3
31	0.109	0	1	1	1	1	3
33	0.109	0	1	1	1	1	3
35	0.109	0	1	1	1	1	3
37	0.109	0	1	1	1	1	3
30	0.109	0	1	1	1	1	3
41	0.109	0	1	1	1	1	3
41	0.109	0	1	1	1	1	3
43	0.109	0	1	1	1	1	3
43	0.109	0	1	1	1	1	2
47	0.109	0	1	1	1	1	2
49 51	0.109	0	1	1	1	1	2
52	0.109	0	1	1	1	1	2
55	0.109	0	1	1	1	1	2
57	0.109	0	1	1	1	1	3
50	0.109	0	1	1	1	1	3
59 61	0.109	0	1	1	1	1	3
63	0.109	0	1	1	1	1	3
65	0.109	0	1	1	1	1	3
67	0.109	0	1	1	1	1	3
69	0.109	0	1	1	1	1	3
71	0.109	Ő	1	1	1	1	3
73	0.109	Ő	1	1	1	1	3
75	0 109	Ő	1	1	1	1	3
77	0 1 0 9	Ő	1	1	1	1	3
79	0.109	Ő	1	1	1	1	3
81	0.109	Ő	1	1	1	1	3
83	0 109	Ő	1	1	1	1	3
85	0.109	Ő	1	1	1	1	3
87	0.109	Ő	1	1	1	1	3
89	0.109	Ő	1	1	1	1	3
91	0.109	Ő	1	1	1	1	3
93	0.109	Ő	1	1	1	1	3
95	0.109	0	1	1	1	1	3
97	0.109	Ő	1	1	1	1	3
99	0.109	Ő	1	1	1	1	3
101	0.109	Ő	1	1	1	1	3
103	0.109	Ő	1	1	1	1	3
105	0.109	Ő	1	1	1	1	3
107	0.109	0	1	1	1	1	3
109	0.109	Ō	1	1	1	1	3
111	0.109	Õ	1	1	1	1	3
113	0.109	Ō	1	1	1	1	3
115	0.109	Ō	1	1	1	1	3
117	0.109	Ō	1	1	1	1	3
119	0.109	0	1	1	1	1	3
122	0.109	0	1	1	1	1	3



eading: fultilayer Cover for Slit Trench Unit - Intact Case - Cao		Geor	netry infor	mation				×	(
fultilayer Cover for Slit Trench Unit - Intact Case - Cao		_ ler	ath Units—						_
	Installation		igar <u>o</u> nia	3	Number of Soil Ma	aterials		OK I	
	on Solution 2		mm	3	 Number of <u>L</u> ayers	for Mass E	Balances	Cancel	il.
Vater Flow	se solution :		m	1	 Decline from ⊻erti	cal Axes		Previous	
Snow Hydrology					(=1: vertical; =0:	horizontal)		<u>N</u> ext	
Standard Solute Transport				122	Depth of the Soil	Profile (cm)	]	Help	il.
C Major Ion Chemistry									
C HP1 (PHREEQC)	UK	[	Time Info	mation				~	,
Heat Iransport (	Cancel		Time mo	mation				^	•
Root Water Uptake	Next		_ Time Unit	s Tim	e Discretization	_			
✓ Root Growth			C Seco	nds <u>I</u> nitia	il Time [day]:	0			
CO2 Transport	Help		◯ <u>M</u> inut	es <u>F</u> ina	l Time [day]:	365	524	Cancel	
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van Genuchten - Mualem			Time-Vari	able Bounda	ry Conditions				
With Air-Entry Value of -2 cm			Time-	<u>/</u> ariable Bou	ndary Conditions				
C Modified van Genuchten		-	36524	l Numbe	r of Time-Variable Bo	oundary <u>R</u> e	ecords (e.g., P	recipitation)	
C Brooks-Corey			□ Be	epeat the sar	ne set of BC records	n times:	1		
C Kosugi (log-normal)				' vilu Variations	of Transpiration Dur	ing Day G	enerated by H		
- Dual-Porosity/Dual-Permeability Models		-		ny vanations pusoidal Vari	tions of Precipitation	ng Day <u>a</u> r Generate	d by HYDBH 9	2	
O Dual-porosity (Durner, dual van Genuchten - Mu	ialem)		01		ations of Pre <u>c</u> ipitation	i denerate	a by hi bhos	,	
C Dual-porosity (mobile-immobile, water c. mass tra	insfer)			orological Da	la Dista				
C Dual-porosity (mobile-immobile, head mass transference)	fer)			ecorological					
== Models below are recommended only for experier	nced users ==		36	524 Nun	ber of Meteorologica	al <u>R</u> ecords	(e.g., Radiatio	n)	
C Dual-permeability (Kinematic wave <u>e</u> quation)				Penman-Mo	ntheith Eguation				
C Dual-permeability (Gerke and van Genuchten, 1	993)		0	Hargreaves	Formuļa				
C Look-up Tables				Energy <u>B</u> ala	nce Boundary Condi	tior _			
Hysteresis		-		Daily Variati	ons of Meteo Data D	uring Day	Generated by	HYDRUS	
No hysteresis		[	Ro	ot Water ai	nd Solute Uptake I	Vodel		×	
O Hysteresis in retention curve			F	loot Water Up	take Model				
<ul> <li>Hysteresis in retention curve and conductivity</li> </ul>				-Water Uptal	ke Reduction Model—			OK	
<ul> <li>Hysteresis in retention curve (no pumping, Bob Ler</li> </ul>	nhard)			Ecological Ecologic					
C Initially drying curve				- Coluto Stree	a Madal			Cancel	
C Initially wetting curve				<ul> <li>Solute Sites</li> <li>Mo Solut</li> </ul>				Previous	
ater Flow Boundary Conditions		X		C Additive	Model				
····· / ·····				C Multiplic	ative Model			<u>N</u> ext	
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Upper Boundary Condition				C S-SI	nap <u>e</u>			Help	
Upper Boundary Condition									
Upper Boundary Condition C Constant Water Content C Constant <u>Fl</u> ux	Cancel			1	Critical Stress Index	for Water	Uptake		
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Upper Boundary Condition C Constant Water Content C Constant <u>Flux</u> C Atmospheric BC with Surface <u>Layer</u> Atmospheric BC with Surface <u>Run</u> Off C Variable Pressure Head	Cancel Previous Next			1 Root Solute U	Critical Stress Index ptake Model	for Water	e Solute Uptak	e etive lintake	
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Upper Boundary Condition Constant Water Content Constant Elux Atmospheric BC with Surface Layer Atmospheric BC with Surface Run Off Variable Pressure Head Variable Pressure Head/Flux Triggered Irrigation	Cancel <u>P</u> revious <u>N</u> ext <u>H</u> elp		Water I	1 Root Solute U Flow Parame	Critical Stress Index ptake Model	for Water	e Solute Uptak	e stive Uptake	
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Upper Boundary Condition C Constant Water Content C Constant Elux Atmospheric BC with Surface Layer Atmospheric BC with Surface Run Off Variable Pressure Head Variable Pressure Head/Flux Triggered Irrigation Lower Boundary Condition	Cancel <u>Previous</u> <u>Next</u> <u>H</u> elp		Water I	1 Root Solute U Flow Parame Qr [-] 0.047	Cgitical Stress Index ptake Model tters Qs [-] Alpha [1 0.396 0.35	for Water	n [-]	e ctive Uptake Ks [cm/day] 267.84	
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Upper Boundary Condition C Constant Water Content C Constant Elux Atmospheric BC with Surface Layer Atmospheric BC with Surface Bun Off Variable Pressure Head Variable Pressure Head/Flux Triggered Irrigation Lower Boundary Condition Lower Boundary Condition C Constant Water Content C Constant Flux Variable Pressure Head Variable Pressure Head Variable Pressure Head Variable Flug Free Drainage	Cancel Previous Next Help ondition essure Heads ater Contents		Water I Mat 1 2 3	1 Root Solute L Clow Parame Qr [-] 0.047 0.181 0.07	Cgitical Stress Index ptake Model tters Qs [-] Alpha [1 0.396 0.35 0.15	t for Water 1 1/cm] 0.075 0.027 0.145	e Solute Uptak Solute with A n [-] 1.89 1.23 2.68	e ctive Uptake Ks [cm/day] 267.84 3.5424 11.23	- I [ + + 3
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Upper Boundary Condition C Constant Water Content C Constant Elux Atmospheric BC with Surface Layer Atmospheric BC with Surface Bun Off Variable Pressure Head Variable Pressure Head Variable Pressure Head C Constant Water Content C Constant Flux C Variable Pressure Head Variable Pressure Head Variable Pressure Head Variable Flux Free Drainage C Deep Drainage C Seepage Face; h = C Motionated Draina	Cancel Previous Next Help ondition essure Heads ater Contents		Water I Mat 1 2 3	1 Root Solute L Ow Parame Qr [-] 0.047 0.181 0.07	Critical Stress Index ptake Model tters Qs [-] Alpha [1 0.396 0.35 0.15	(ror Water 	e Solute Uptak Solute with A n [-] 1.89 1.23 2.68	e ctive Uptake Ks [cm/day] 267.84 3.5424 11.23 onIemperature	1 [ 1 ] 1 ] 1 ] 1 ] 1 ] 1 ] 1 ] 1 ]
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\* The Soil Profile Summary, Time Variable Boundary Conditions (ATMOSPH – Master.IN), and Meteorological Conditions (METEO.IN) screen captures show only a small portion of the total input dataset due to their large size.

<u>Case 3-3 – Soil Profile Summary</u>

z[cm]	theta	Root[1/cm]	Axz	Bxz	Dxz	Mat	Layer
0	0.109	0	1	1	1	1	ĺ
1.22	0.109	0	1	1	1	1	1
2.44	0.109	0	1	1	1	1	1
3.66	0.109	0	1	1	1	1	1
4.88	0.109	0	1	1	1	1	1
6.1	0.109	0	1	1	1	1	1
7.32	0.109	Ő	1	1	1	1	1
8 54	0 109	Ő	1	1	1	1	1
9.76	0 109	Ő	1	1	1	1	1
10.98	0.109	Ő	1	1	1	1	1
12.2	0.109	0	1	1	1	1	1
13.42	0.109	0	1	1	1	1	1
14 64	0.109	0	1	1	1	1	1
15.24	0.109	0	1	1	1	1	1
17.08	0.109	0	1	1	1	2	2
17.00	0.252	0	1	1	1	2	2
10.5	0.252	0	1	1	1	2	2
19.32	0.232	0	1	1	1	2	2
20.74	0.252	0	1	1	1	2	2
21.90	0.252	0	1	1	1	2	2
23.18	0.252	0	1	1	1	2	2
24.4	0.252	0	1	l	1	2	2
25.62	0.252	0	I	l	I	2	2
26.84	0.252	0	1	1	1	2	2
28.06	0.252	0	1	1	1	2	2
29.28	0.252	0	1	1	1	2	2
30.5	0.252	0	1	1	1	2	2
31.72	0.252	0	1	1	1	2	2
32.94	0.252	0	1	1	1	2	2
34.16	0.252	0	1	1	1	2	2
35.38	0.252	0	1	1	1	2	2
36.6	0.252	0	1	1	1	2	2
37.82	0.252	0	1	1	1	2	2
39.04	0.252	0	1	1	1	2	2
40.26	0.252	0	1	1	1	2	2
41.48	0.252	0	1	1	1	2	2
42.7	0.252	0	1	1	1	2	2
43.92	0.252	0	1	1	1	2	2
45.14	0.252	0	1	1	1	2	2
46.36	0.252	0	1	1	1	2	2
47.58	0.252	0	1	1	1	2	2
48.8	0.252	0	1	1	1	2	2
50.02	0.252	0	1	1	1	2	2
51.24	0.252	0	1	1	1	2	2
52.46	0.252	0	1	1	1	2	2
53.68	0.252	0	1	1	1	2	2
54.9	0.252	0	1	1	1	2	2
56.12	0.252	Ő	1	1	1	2	2
57.34	0.252	Ő	1	1	1	$\frac{1}{2}$	2
58.56	0.252	Ő	1	1	1	$\frac{1}{2}$	$\frac{1}{2}$
59 78	0.252	Õ	1	1	1	2	2
61	0.252	Õ	1	1	1	$\frac{2}{2}$	$\frac{1}{2}$
62 22	0.252	0	1	1	1	$\frac{1}{2}$	$\frac{2}{2}$
63.44	0.252	õ	1	1	1	2	2

$\begin{array}{cccccccccccccccccccccccccccccccccccc$	z[cm]	theta	Root[1/cm]	Axz	Bxz	Dxz	Mat	Layer
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	64.66	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	65.88	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	67.1	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	68.32	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	69.54	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	70.76	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	71.98	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	73.2	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	74.42	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	75.64	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	76.86	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	78.08	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	79.3	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	80.52	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	81.74	0.252	0	1	1	1	2	2
84.18 $0.252$ $0$ $1$ $1$ $1$ $2$ $2$ $85.4$ $0.252$ $0$ $1$ $1$ $1$ $2$ $2$ $86.62$ $0.252$ $0$ $1$ $1$ $1$ $2$ $2$ $87.84$ $0.252$ $0$ $1$ $1$ $1$ $2$ $2$ $90.28$ $0.252$ $0$ $1$ $1$ $1$ $2$ $2$ $91.44$ $0.252$ $0$ $1$ $1$ $1$ $2$ $2$ $92.72$ $0.100$ $0$ $1$ $1$ $1$ $3$ $3$ $95.16$ $0.100$ $0$ $1$ $1$ $1$ $3$ $3$ $96.38$ $0.100$ $0$ $1$ $1$ $1$ $3$ $3$ $97.6$ $0.100$ $0$ $1$ $1$ $1$ $3$ $3$ $100.04$ $0.100$ $0$ $1$ $1$ $1$ $3$ $3$ $102.48$ $0.100$ $0$ $1$ $1$ $1$ $3$ $3$ $102.48$ $0.100$ $0$ $1$ $1$ $1$ $3$ $3$ $104.92$ $0.100$ $0$ $1$ $1$ $1$ $3$ $3$ $107.36$ $0.100$ $0$ $1$ $1$ $1$ $3$ $3$ $108.58$ $0.100$ $0$ $1$ $1$ $1$ $3$ $3$ $11.46$ $0.100$ $0$ $1$ $1$ $1$ $3$ $3$ $11.46$ $0.100$ $0$ $1$ $1$ $1$ $3$ $3$ <td>82.96</td> <td>0.252</td> <td>0</td> <td>1</td> <td>1</td> <td>1</td> <td>2</td> <td>2</td>	82.96	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	84.18	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	85.4	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	86.62	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	87.84	0.252	Ő	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	89.06	0.252	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	90.28	0.252	Ő	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	91 44	0.252	Ő	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	92.72	0.100	Ő	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	93 94	0.100	Ő	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	95.16	0 100	Ő	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	96 38	0.100	Ő	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	97.6	0.100	Ő	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	98.82	0.100	Ő	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	100.04	0.100	Ő	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	101.26	0.100	0	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	101.20	0.100	0	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	102.40	0.100	0	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	10/ 02	0.100	0	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	104.92	0.100	0	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	107.36	0.100	0	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	107.50	0.100	0	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	100.58	0.100	0	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	111.02	0.100	0	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	112.02	0.100	0	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	112.24	0.100	0	1	1	1	3	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	114.68	0.100	0	1	1	1	2	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	115.00	0.100	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	117.7	0.100	0	1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	118 2/	0.100	0	1 1	1	1	2	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	110.34	0.100	0	1 1	1	1	2	2
120.70 0.100 0 1 1 1 3 3 1 1 1 2 2	120.78	0.100	0	1	1	1	2	3
	120.70	0.100	0	1	1	1	3	2



Main Processes	XG	eometry Informa	ation	×
Heading		Length Units		
Multilayer Cover with Drainage Layer - Intact Case - Time 0		C mm	4 Number of Soil <u>M</u> aterials	OK.
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☐ <u>V</u> apor Flow		0 m	[1] [=1: vertical; =0: horizontal]	
Snow Hydrology				<u>N</u> ext
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Cance		<b>T</b> 11 5	The second second	
<u>Next</u>			I ime Discretization	
I Root Growth		O Second	s Initial Lime (day):	Canad
		C <u>M</u> inutes	Einal Time [day]:	524 Lancei
		C Hours	Initial Time Step (day): 0.0	01 <u>Previous</u>
Soil Hydraulic Model		<u> </u>	Minimum Time Step [day]: 1e	005 <u>N</u> ext
- Hudraulie Model		O Years	Maximum Time Step [day]: 0.0	)1 <u>H</u> elp
Single Porosity Models				
van Genuchten - Mualem		Time-Variabl	ie Boundary Conditions	
With Air-Entry Value of -2 cm	Ca	ncel I I I I I I I I I I I I I I I I I I I	riable Boundary Conditions —	
C Modified van Genuchten		36524	Number of Time-Variable Boundary B	ecords (e.g., Precipitation)
C Brooks-Corey	<u>P</u> revi	ous 📃 Repa	eat the same set of BC records n times:	1
C Kosugi (log-normal)	N	🔽 Dailu	Variations of Transpiration During Day G	enerated by HYDBUS
Dual-Porosity/Dual-Permeability Models		st Sinus	soidal Variations of Precipitation Generate	ed by HYDBUS
O Dual-porosity (Durner, dual van Genuchten - Mualem)	Н	elp Meteoro	logical Data	
C Dual-poro <u>s</u> ity (mobile-immobile, water c. mass transfer)		Meteoro	prological Data	
U Duai-porosity (mobile-immobile, head mass transfer)		3652	4 Number of Meteorological Records	(e.g. Padiation)
== Models below are recommended only for experienced u	isers ==	( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( )	A Multiple of Meteorological <u>H</u> ecolds	(e.g., madiation)
C Dual-permeability (Kinematic wave equation)			erman-Monthelin Eguation	
U Duai-permeability (Gerke and Van Genuchten, 1993)			argreaves normaja pergu Balance Boundary Condition	
C Look-up Lables			aily Variations of Meteo Data During Day	Generated by HYDBUS
Hysteresis				
• No hysteresis				-
Hysteresis in retention curve     Hysteresis in retention curve and conductivity			Water Flow Boundary Conditions	×
C Hysteresis in retention curve (no pumping, Bob Lenhard)			Upper Boundary Condition	
C Initially drying curve			C Constant Water Content	OK
C Initially wetting curve			C Constant <u>Flux</u>	Cancel
			C Atmospheric BC with Surface Lave	
Water Flow Parameters		×	Atmospheric BC with Surface Run	Off Previous
	-		C Variable Pressure Head	Next
Mat Qr [-] Qs [-] Alpha [1/cm] n [	-] Ks [cm/day]	I [-]	O Variable Pressure Head/Flux	
1 0.047 0.396 0.075	1.89 267	.84 0.5		<u>H</u> elp
2 0.181 0.35 0.027	1.23 3.5	424 0.5	- inggored ingetion	
<u> </u>	2.08 11	320 0.5	Lower Boundary Condition	Initial Condition
- 0.010 0.17 0.0555	5.1750 4	525 0.5	C Constant Water Content	In Pressure Heads
			C Constant Flux	
			○ Variable Pressure Head	
			C Variable Flu <u>x</u>	
			C Free Drainage	
Soil Catalog	Prediction Tempera	ture Dependence	C Deep Drainage	
		o o openadorido	O Seepage Face; h =	
Cancel Previous	<u>N</u> ext	Help	Horizontal Drains	

### SRNL-STI-2019-00362 Revision 0

#### Case 3-4 - Upper Four Layers of Intact Multilayer Cover



Root Water U	Iptake Parame	eters ×
Feddes' Parar	neters	·····
P <u>0</u> [cm]	0	
POp <u>t</u> [cm]	-1	Cancel
P2 <u>H</u> [cm]	-300	Previous
P2 <u>L</u> [cm]	-1000	Next
P <u>3</u> [cm]	-16000	
<u>r</u> 2H [cm/day]	0.5	<u>H</u> elp
<u>r</u> 2L [cm/day]	0.1	
Database		•

Х

•

Mat 

1

1

<u>H</u>elp

Case $3-4 - U^{\dagger}$	ppe	r Four I	Laye	rs of	Intact	Multila	yer	Cover
			_					

🔚 МЕТЕ	EO.IN 🔟						
23	Inter	cept:	ion				^
24	0						
25	CropHe:	ight	Albedo	LAI	rRoot		
26		30	0.23	3.5	0		
27	Daily v	value	es				
28		t	Rad	TMax	TMin	RHMean	Wind
29		[T]	[MJ/m2/d]	[C]	[C]	[%]	[km/d]
30		1	9	18.9	14.4	68	250
31		2	9	13.9	8.9	68	250
32		3	9	14.4	7.2	68	250
33		4	9	20	13.9	68	250
34		5	9	16.7	8.9	68	250
35		6	9	21.1	10.6	68	250
36		7	9	20	10	68	250
37		8	9	18.3	7.8	68	250
38		9	9	24.4	12.2	68	250
39		10	9	22.8	15.6	68	250
40		11	9	22.2	16.7	68	250
41		12	9	18.3	6.7	68	250
42		13	9	10	0.6	68	250
43		14	9	5	2.8	68	250
44		15	9	16.1	4.4	68	250
45		16	9	22.2	13.9	68	250
46		17	9	24.4	13.9	68	250
47		18	9	15.6	8.9	68	250
48		19	9	15.6	8.3	68	250
49		20	9	15.6	10.6	68	250
50		21	9	23.3	11.1	68	250
51		22	9	25	6.7	68	250
52		23	9	23.3	11.1	68	250
53		24	9	26.1	14.4	68	250
54		25	9	24.4	17.2	68	250 🗸
<							>
-		_					

length : 2,886,820 lines : 3( Ln : 1 Col : 1 Sel : 0 | 0 Windows (CR LF) UTF-8

2 3	*** BLC	DCK I:	ATMOSI	PHERIC	INFORMATI	ON	****	* * * * *	4		z [cm]	theta	Root [1/cm	Axz	Bxz	Dx
Ľ	MaxA	AL			(MaxAI	=	numbe	r of	a	1	0	0.109	0	1	1	
	36524	1								2	2.58896	0.109	0	1	1	
	Daily	/ar Si	inusVa	r lLa	ay lBCCycl	es	lInte	rc 10	n I	3	4.69746	0.109	0	1	1	
		t	f	t	f f		f		1	4	6.80597	0.109	0	1	1	
	hCrits	3			(max. allo	wed	pres	sure	ł	5	8.91448	0.109	0	1	1	
	0	)								6	11.023	0.109	0	1	1	
		tAtm		Prec	rSoi	1	:	rRoot		7	13.1315	0.109	0	1	1	
	1	0.00	0	0	1.00E+06	0	0	0		8	15.24	0.109	0	1	1	
	2	0.00	0	0	1.00E+06	0	0	0		9	17.3485	0.252	0	1	1	
	3	0.00	0	0	1.00E+06	0	0	0		10	18.995	0.252	0	1	1	
	4	0.00	0	0	1.00E+06	0	0	0		11	20.6415	0.252	0	1	1	
	5	0.00	0	0	1.00E+06	0	0	0		12	22.2879	0.252	0	1	1	
	6	0.00	0	0	1.00E+06	0	0	0		13	23.9344	0.252	0	1	1	
	7	0.00	0	0	1.00E+06	0	0	0		14	25.5809	0.252	0	1	1	
	8	0.00	0	0	1.00E+06	0	0	0		15	27.2274	0.252	0	1	1	
	9	0.00	0	0	1.00E+06	0	0	0		16	28.8738	0.252	0	1	1	
	10	0.00	0	0	1.00E+06	0	0	0								
	11	0.00	0	0	1.00E+06	0	0	0		[	OK I	Connel	1		Mauk	1
	12	0.00	0	0	1.00E+06	0	0	0		<u> </u>		Cancel	<u> </u>	revious	<u>N</u> ext	
	13	0.00	0	0	1.00E+06	0	0	0								
	14	0.51	0	0	1.00E+06	0	0	0								
	15	0.08	0	0	1.00E+06	0	0	0								
	16	0.00	0	0	1.00E+06	0	0	0								
	17	0.00	0	0	1.00E+06	0	0	0								
	18	0.00	0	0	1.00E+06	0	0	0								
	19	0.00	0	0	1.00E+06	0	0	0								
	20	0.05	0	0	1.00E+06	0	0	0								
	21	0.00	0	0	1.00E+06	0	0	0								

\* The Soil Profile Summary, Time Variable Boundary Conditions (ATMOSPH - Master.IN), and Meteorological Conditions (METEO.IN) screen captures show only a small portion of the total input dataset due to their large size.

## <u>Case 3-4 – Soil Profile Summary</u>

z[cm]	theta	Root[1/cm]	Axz	Byz	Dyz	Mat	Laver
0.0	0 109	0	1	1	1	1	1
2 58896	0.109	0	1	1	1	1	1
2.50050 4.60746	0.109	0	1	1	1	1	1
6 80597	0.109	0	1	1	1	1	1
0.80 <i>391</i> 8 01 <i>44</i> 8	0.109	0	1	1	1	1	1
0.91440	0.109	0	1	1	1	1	1
11.025	0.109	0	1	1	1	1	1
15.1515	0.109	0	1	1	1	1	1
15.24	0.109	0	1	1	1	1	1
17.3485	0.252	0	1	1	1	2	2
18.995	0.252	0	1	l	1	2	2
20.6415	0.252	0	l	l	l	2	2
22.2879	0.252	0	1	1	1	2	2
23.9344	0.252	0	1	1	1	2	2
25.5809	0.252	0	1	1	1	2	2
27.2274	0.252	0	1	1	1	2	2
28.8738	0.252	0	1	1	1	2	2
30.5203	0.252	0	1	1	1	2	2
32.1668	0.252	0	1	1	1	2	2
33.8133	0.252	0	1	1	1	2	2
35.4598	0.252	0	1	1	1	2	2
37.1062	0.252	0	1	1	1	2	2
38.7527	0.252	0	1	1	1	2	2
40.3992	0.252	0	1	1	1	2	2
42.0457	0.252	0	1	1	1	2	2
43.6922	0.252	Õ	1	1	1	2	2
45 3386	0 2 5 2	Ō	1	1	1	2	2
46 9851	0.252	Ő	1	1	1	2	2
48 6316	0.252	Ő	1	1	1	2	2
50 2781	0.252	Ő	1	1	1	2	2
51 9245	0.252	ů 0	1	1	1	2	2
53 571	0.252	0	1	1	1	$\frac{2}{2}$	$\frac{2}{2}$
55 2175	0.252	0	1	1	1	2	2
56 861	0.252	0	1	1	1	2	2
58 5104	0.252	0	1	1	1	2	2
60 1560	0.252	0	1	1	1	2	2
00.1309	0.232	0	1	1	1	2	2
01.8034	0.252	0	1	1	1	2	2
03.4499	0.252	0	1	1	1	2	2
65.0964	0.252	0	1	1	1	2	2
66./428	0.252	0	1	1	1	2	2
68.3893	0.252	0	1	l	1	2	2
70.0358	0.252	0	l	l	l	2	2
71.6823	0.252	0	1	1	1	2	2
73.3287	0.252	0	1	1	1	2	2
74.9752	0.252	0	1	1	1	2	2
76.6217	0.252	0	1	1	1	2	2
78.2682	0.252	0	1	1	1	2	2
79.9147	0.252	0	1	1	1	2	2
81.5611	0.252	0	1	1	1	2	2
83.2076	0.252	0	1	1	1	2	2
84.8541	0.252	0	1	1	1	2	2
86.5006	0.252	0	1	1	1	2	2
88.147	0.252	0	1	1	1	2	2
89.7935	0.252	0	1	1	1	2	2

z[cm]	theta	Root[1/cm]	Axz	Bxz	Dxz	Mat	Laver
91.44	0.252	0	1	1	1	2	2
93.0865	0.100	Ő	1	1	1	3	3
94.7826	0.100	0	1	1	1	3	3
96 4787	0 100	Ő	1	1	1	3	3
98 1747	0 100	Ő	1	1	1	3	3
99 8708	0.100	0	1	1	1	3	3
101 567	0.100	0	1	1	1	3	3
103.263	0.100	0	1	1	1	3	3
104 959	0.100	0	1	1	1	3	3
104.55	0.100	0	1	1	1	3	3
108.351	0.100	0	1	1	1	3	3
110.047	0.100	0	1	1	1	2	2
111.047	0.100	0	1	1	1	2	2
111./45	0.100	0	1	1	1	2	2
115.44	0.100	0	1	1	1	2	2
115.150	0.100	0	1	1	1	2	2
110.832	0.100	0	1	1	1	3	2
118.528	0.100	0	1	1	1	3	2
120.224	0.100	0	1	1	1	3	3
121.92	0.100	0	1	1	1	3	3
123.616	0.045	0	1	1	1	4	4
126.019	0.045	0	l	l	1	4	4
128.224	0.045	0	l	1	1	4	4
130.246	0.045	0	l	1	l	4	4
132.102	0.045	0	l	1	l	4	4
133.804	0.045	0	l	l	l	4	4
135.366	0.045	0	1	1	1	4	4
136.798	0.045	0	1	1	1	4	4
138.113	0.045	0	1	1	1	4	4
139.319	0.045	0	1	1	1	4	4
140.425	0.045	0	1	1	1	4	4
141.44	0.045	0	1	1	1	4	4
142.372	0.045	0	1	1	1	4	4
143.226	0.045	0	1	1	1	4	4
144.01	0.045	0	1	1	1	4	4
144.729	0.045	0	1	1	1	4	4
145.389	0.045	0	1	1	1	4	4
145.994	0.045	0	1	1	1	4	4
146.549	0.045	0	1	1	1	4	4
147.059	0.045	0	1	1	1	4	4
147.526	0.045	0	1	1	1	4	4
147.955	0.045	0	1	1	1	4	4
148.348	0.045	0	1	1	1	4	4
148.709	0.045	0	1	1	1	4	4
149.04	0.045	0	1	1	1	4	4
149.344	0.045	0	1	1	1	4	4
149.622	0.045	0	1	1	1	4	4
149.878	0.045	0	1	1	1	4	4
150.113	0.045	0	1	1	1	4	4
150.328	0.045	0	1	1	1	4	4
150.525	0.045	0	1	1	1	4	4
150.706	0.045	0	1	1	1	4	4
150.872	0.045	0	1	1	1	4	4
151.025	0.045	0	1	1	1	4	4
151.165	0.045	0	1	1	1	4	4
151.293	0.045	0	1	1	1	4	4

z[cm]	theta	Root[1/cm]	Axz	Bxz	Dxz	Mat	Layer
151.411	0.045	0	1	1	1	4	4
151.519	0.045	0	1	1	1	4	4
151.618	0.045	0	1	1	1	4	4
151.709	0.045	0	1	1	1	4	4
151.792	0.045	0	1	1	1	4	4
151.869	0.045	0	1	1	1	4	4
151.939	0.045	0	1	1	1	4	4
152.003	0.045	0	1	1	1	4	4
152.062	0.045	0	1	1	1	4	4
152.116	0.045	0	1	1	1	4	4
152.166	0.045	0	1	1	1	4	4
152.212	0.045	0	1	1	1	4	4
152.254	0.045	0	1	1	1	4	4
152.292	0.045	0	1	1	1	4	4
152.327	0.045	0	1	1	1	4	4
152.36	0.045	0	1	1	1	4	4
152.389	0.045	0	1	1	1	4	4

## Appendix C. HYDRUS-1D Output

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### Case 3-1a - Operational Soil Cover (Annual Weather Data)

<sup>a</sup> Inches/year = Cumulative [cm] / 100 years / 2.54 cm/inch



<sup>c</sup> Cum. Bottom Flux = Cum. Percolation Rate

<sup>d</sup> Cum. Evaporation  $\equiv$  Cum. Evapotranspiration



#### Case 3-1b - Operational Soil Cover (Daily Weather Data)

<sup>a</sup> Inches/year = Cumulative [cm] / 100 years / 2.54 cm/inch



<sup>c</sup> Cum. Bottom Flux = Cum. Percolation Rate

<sup>d</sup> Cum. Evaporation = Cum. Evapotranspiration





<sup>a</sup> Inches/year = Cumulative [cm] / 100 years / 2.54 cm/inch



<sup>c</sup> Cum. Bottom Flux = Cum. Percolation Rate

<sup>d</sup> Cum. Evaporation = Cum. Evapotranspiration





<sup>a</sup> Inches/year = Cumulative [cm] / 100 years / 2.54 cm/inch

<sup>b</sup> Cum. Precipitation = Cum. Root Water Uptake + Cum. Evaporation + Cum. Surface Run-Off + Cum. Bottom Flux

<sup>c</sup> Cum. Bottom Flux = Cum. Percolation Rate

<sup>d</sup> Cum. Evaporation = Cum. Evapotranspiration



### Case 3-3 - Upper Three Layers of Intact Multilayer Cover

<sup>a</sup> Inches/year = Cumulative [cm] / 100 years / 2.54 cm/inch



<sup>c</sup> Cum. Bottom Flux = Cum. Percolation Rate

<sup>d</sup> Cum. Evaporation  $\equiv$  Cum. Evapotranspiration


## Case 3-4 - Upper Four Layers of Intact Multilayer Cover

<sup>a</sup> Inches/year = Cumulative [cm] / 100 years / 2.54 cm/inch

- <sup>b</sup> Cum. Precipitation = Cum. Root Water Uptake + Cum. Evaporation + Cum. Surface Run-Off + Cum. Bottom Flux
- <sup>c</sup> Cum. Bottom Flux  $\equiv$  Cum. Percolation Rate
- <sup>d</sup> Cum. Evaporation  $\equiv$  Cum. Evapotranspiration

Appendix D. HELP Model Input Parameters for Slit-and-Engineered-Trench Cases used in HYDRUS-1D Comparisons This Page Intentionally Blank

Table D-1. HELP Model Input Data for Case 3-1 – Operational Soil Cover
(ST_OpCover.D10).

Input Parameter (HELP Model Query)								Generic Input Parameter Value								
Landfil	/		0.0689 acres													
Percent	t of area v	where runoff is	possił	ole =			100%									
Do you	Υ															
Amoun	0 inches															
CN Inp	uery)	CN Input Parameter Value														
Slope =								1%								
Slope length =								80 ft								
Soil Texture =							4 (HELP model default soil texture)									
Vegetation =							4 (i.e., a good stand of grass)									
HELP Model Computed Curve Number = 53.06																
Layer Layer Number								Layer Type								
Topsoil	1		1					1 (vertic	al p	ercolatio	n lay	er)				
	1		1		1											
Layer	Layer	Layer	Soil		Tota		Fiel	ld Wilting		ilting		Initial				
#	Туре	Thickness	Tex	ture	Poro	sity	Cap	acity Po		oint		Moisture <sup>2</sup>				
		(1n)	No.		(Vol	(Vol)	(Vo	//Vol) (Vol/		ol/Vol)	(	(Vol/Vol)				
1	1	48			0.396	6 0.1		0.04		)47		0.109				
Lavor	Louar	Sat Und	Г	raina		Drain		Lanahata		Daaira	to	Subaurfago				
Hayer	Type	Conductivity		enatl	ige	Slope		Recirc		Laver	. 10	Inflow				
π	rype	(cm/sec)		engu 7)	1	(%)		(%)		(#)		(in/yr)				
1	1	1 0E-03	(	.()		(70)		(70)		(")		(III/ y1)				
1	1	1.02 05														
Laver	Laver	Geomembran	e	G	eomen	ıbrane In	stal.	Geomem	bra	ne	Geo	otextile				
#	Type	Pinhole Dens	itv	D	efects			Placemen	nt O	uality	Tra	nsmissivitv				
	-76-	(#/acre)	.,	(#	/acre)			(cm <sup>2</sup> /sec)				$\frac{1}{2}$ /sec)				
									/							

Table D-2. HELP Model Input Data for Case 3-2 – Institutional Control
(ST_IC.D10).

Input Parameter (HELP Model Query)								Generic Input Parameter Value							
Landfil	0.0689 acres														
Percent	of area	where runoff is	possib	le =			100%								
Do you	want to	specify initial n	noistur	e sto	rage?	(Y/N)	Y								
Amoun	t of wate	r or snow on su	rface =	=	U	×	0 inches								
CN Inp	CN Input Parameter Value														
Slope =								2%							
Slope length =								585 ft							
Soil Texture =								4 (HELP model default soil texture)							
Vegetation =								4 (i.e., a good stand of grass)							
HELP Model Computed Curve Number = 46.2								Bood Sunta of Braddy							
Layer		1	Layer	Nun	nber		Layer Type								
Topsoil	[		1					1 (vertic	al p	ercolatio	n lave	er)			
GCL			2					4 (geom	emt	orane line	er)	/			
Topsoil			3					1 (vertic	al p	ercolatio	n lave	er)			
10000			2					1 ( ) 01 010	p						
Laver	Laver	Laver	Soil		Tota	1	Fiel	d	W	ilting	I	Initial			
#	Type	Thickness	Text	ure	Poro	sitv	Capacity Po			Point I		Moisture <sup>2</sup>			
	- 7 F -	(in)	No.		(Vol/	/Vol)	(Vol/Vol) (Vol/Vol			ol/Vol)	(	(Vol/Vol)			
1	1	0.0001			0.396	5	0.109		0.047		(	0.109			
2	4	0.06			0.75	-	0.74	47	0.4		(	).75			
3	1	48		0.396		5	0.109		0.047		(	0.109			
						-			-						
Laver	Laver	Sat. Hvd.	D	raina	ge	Drain	1	Leachate		Recirc	. to	Subsurface			
#	Type	Conductivity	Le	ength	n 1	Slope		Recirc.	c. Layer (#)			Inflow			
	51	(cm/sec)	(ft	)		(%)		(%)				(in/yr)			
1	1	1.0E-03													
2	4	5.0E-08													
3	1	1.0E-03													
Layer	Layer	Geomembran	e	G	eomen	nbrane In	stal.	Geomem	bra	ne	Geo	textile			
#	Type Pinhole Density Defects						Placement Quality Transmiss				nsmissivity				
		(#/acre)	-	(#	/acre)		(cm <sup>2</sup> /sec				<sup>2</sup> /sec)				
2	4	1 4					3								

## Table D-3. HELP Model Input Data for Case 3-3 – Upper Three Layers at Time of Cap Installation(ST3L00.D10).

Input Parameter (HELP Model Query)								Generic Input Parameter Value						
Landfil	l area =						0.2686 acres							
Percent	of area v	where runoff is	possi	ble =			100%							
Do you	want to	specify initial r	noisti	are sto	orage?	(Y/N)	Y							
Amoun	t of wate	r or snow on su	rface	=			0 inches							
CN Inp	ut Param	eter (HELP Mo	odel (	Query	CN Input Parameter Value									
Slope =	=				2 %									
Slope le	ength =				585 ft									
Soil Te	xture =		4 (HELP model default soil texture)											
Vegetat	tion =		4 (i.e., a good stand of grass)											
HELP I	Model Co	omputed Curve	Num	ber =	46.2									
Layer			Laye	er Nur	nber			Layer T	ype					
Topsoil	l		1					1 (vertic	al p	ercolatio	on lay	er)		
Upper l	Backfill		2					1 (vertic	al p	ercolatio	on lay	er)		
Erosior	n Barrier		3					1 (vertic	al p	ercolatio	on lay	er)		
			1				1							
Layer	Layer	Layer	Soi	1	Tota	1	Field Wilting			ilting	]	Initial		
#	Туре	Thickness	Теу	ture	Poro	sity	Capacity P			Point I		Moisture <sup>2</sup>		
		(in)	No	•	(Vol	/Vol)	(Vo	(Vol/Vol) (Vol/Vol			(	(Vol/Vol)		
1	1	6			0.396	5	0.10	0.109 0.047		)47	(	0.109		
2	1	30			0.35		0.252		0.181		(	0.252		
3	1	12			0.15		0.1		0.07		(	0.1		
												-		
Layer	Layer	Sat. Hyd.	I	Draina	age	Drain		Leachate		Recirc	. to	Subsurface		
#	Туре	Conductivity	I	Lengt	h	Slope	Recirc. Laye			Layer		Inflow		
		(cm/sec)	(	(ft)		(%)		(%)		(#)		(in/yr)		
1	1	3.1E-03												
2	1	4.1E-05												
3	1	1.3E-04												
	_													
Layer	Layer	Geomembran	e	G	eomen	nbrane In	stal.	Geomem	brai	ne	Geo	textile		
#	Туре	Pinhole Dens	ity	D	efects		Placement Quality Transmissivity					nsmissivity		
		(#/acre)	-	(#	#/acre)			(cm <sup>2</sup> /sec)						
											-			

## Table D-4. HELP Model Input Data for Case 3-4 – Upper Four Layers at Time of Cap Installation(ST4L00.D10).

Input Parameter (HELP Model Query)								Generic Input Parameter Value						
Landfil	l area =						0.2686 acres							
Percent	of area v	where runoff is	poss	sible	=		100%							
Do you	want to	specify initial 1	noist	ture s	Y									
Amoun	t of wate	r or snow on su	ırfac	e =	0 inches									
CN Inp	ut Param	eter (HELP M	odel	Quer	CN Input Parameter Value									
Slope =	=				2 %									
Slope le	ength =				585 ft									
Soil Te		4 (HELP model default soil texture)												
Vegetat		4 (i.e., a good stand of grass)												
HELP I	nber													
Layer			Lay	ver N	umber		Layer Type							
Topsoil	[		1					1 (vertic	al p	ercolatio	on lay	er)		
Upper l	Backfill		2					1 (vertic	al p	ercolatio	n lay	er)		
Erosion	n Barrier		3					1 (vertic	al p	ercolatio	n lay	er)		
Lateral	Drainage	e Layer	4					2 (latera	l dra	ainage la	ver)			
	8	~									~ /			
-														
Layer	Layer	Layer	Sc	oil	Tot	al	Field Wilting				Initial			
#	Туре	Thickness	Τe	exture	e Por	osity	Capacity			Point I		Moisture <sup>2</sup>		
	• 1	(in)	No	o.	(Vo	l/Vol)	(Vo	(Vol/Vol) (Vol/Vol				(Vol/Vol)		
1	1	6			0.39	96	0.109		0.047			0.109		
2	1	30			0.35	5	0.252		0.181			0.252		
3	1	12			0.15	5	0.1	1		0.07		0.1		
4	2	12			0.4	17	0.045 0.0			018		0.045		
-														
Laver	Laver	Sat. Hvd.		Drai	nage	Drain		Leachate	;	Recirc	. to	Subsurface		
#	Type	Conductivity		Leng	eth	Slope		Recirc. Laver				Inflow		
	71	(cm/sec)		(ft)	5	(%)		(%)	%) (#)			(in/vr)		
1	1	3.1E-03		()		()		( )		()		( )-)		
2	1	4.1E-05	-+											
3	1	1.3E-04												
4	2	5.0E-02		585		2								
-	-	3.02 02	-+	200		-								
			-+											
			-+											
			-+											
Laver	Laver	Geomembra	ne		Geome	mbrane In	stal	Geomer	bra	ne	Geo	otextile		
#	# Type Pinhole Density Defects							Placement Quality Transmissi			nsmissivity			
	- 750	(#/acre)			(#/acre	)		(cm <sup>2</sup> /sec)						
											(911			

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