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UNSAT-H Infiltration Model Calibration at the Subsurface Disposal Area, Idaho National Engineering Laboratory

P. Martian

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UNSAT-H Infiltration Model Calibration at the Subsurface Disposal Area, Idaho National Engineering Laboratory

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October 1995

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ABSTRACT

Soil moisture monitoring data from the expanded neutron probe monitoring network located at the Subsurface Disposal Area (SDA) of the Idaho National Engineering Laboratory (INEL) were used to calibrate numerical infiltration models for 15 locations within and near the SDA. These calibrated models were then used to simulate infiltration into the SDA surficial sediments and underlying basalts for the entire operational period of the SDA (1952-1995). The purpose of performing the simulations was to obtain a time variant infiltration source term for future subsurface pathway modeling efforts as part of baseline risk assessment or performance assessments.

The simulation results also provided estimates of the average recharge rate for the simulation period and insight into infiltration patterns at the SDA. These results suggest that the average aquifer recharge rate below the SDA may be at least 8 cm/yr and may be as high as 12 cm/yr. These values represent 38 and 57 percent of the average annual precipitation occurring at the INEL, respectively. The simulation results also indicate that the maximum evaporative depth may vary between 28 and 148 cm and is highly dependent on localized lithology within the SDA.

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UNSAT-H Infiltration Model Calibration at the Subsurface Disposal Area, Idaho National Engineering Laboratory

1. INTRODUCTION

1.1 Background

The Radioactive Waste Management Complex (RWMC) located in the southwestern portion of the Idaho National Engineering Laboratory (INEL) has been used for disposal and storage of wastes generated by national defense and nuclear reactor research programs since 1952.

The INEL is located along the western edge of the Eastern Snake River Plain, which encompasses most of the southeastern portion of Idaho and occupies approximately 890 mi². The RWMC encompasses about 144 acres and is situated in a shallow depression surrounded by low hills. The RWMC is divided into two major areas: (a) the Subsurface Disposal Area (SDA) where low-level radioactive and other hazardous wastes are buried in shallow pits and (b) the Transuranic Storage Area where transuranic wastes are stored above ground on covered pads. Between 1954 and 1970, about 6,500 m³ of transuranic waste were disposed in the shallow pits and trenches excavated in the surficial sediments. The location of the RWMC within the INEL and Snake River Plain is illustrated in Figure 1.

1.2 Motivation

Infiltration is the process in which surface water enters the soil. Infiltrating water moving down through the buried wastes, mobilizing contaminants, and eventually transporting them to the aquifer is one of the most realistic scenarios for aquifer contamination beneath the SDA. Therefore, infiltration is an important factor controlling contaminant migration because it is primarily responsible for the amount of dissolution and transport of contaminants away from the waste disposal pits.

Because the migration of contaminants could result in atmosphere and aquifer contamination, a significant amount of effort has been devoted to investigate potential pathways for contaminant migration. These investigations have included both field and modeling studies. One such field study consisted of a vadose zone monitoring program, which was conducted to characterize infiltration at the SDA (McElroy, 1990). From 1985 to 1987, a network of vadose zone instruments were installed at the SDA. The instrumentation included neutron probe access tubes (NATs) and tensiometers. Two NATs (W02 and W06) were regularly monitored for moisture content, and matric potentials were monitored near NAT W06 and W02 (see Figure 2).

The analysis by McElroy (1990) indicated that a substantial portion of the cumulative precipitation infiltrated into the sediments and that the infiltration patterns at the SDA may be highly variable. Additional monitoring of the two NATs in 1992 and 1993 confirmed the earlier findings of both substantial and variable infiltration (McElroy, 1993). The very different infiltration patterns observed in NATs W02 and W06 prompted the installation of additional neutron access tubes. In 1994, the SDA moisture monitoring network was expanded from two to 17 holes (Bishop, 1994). In addition, the USGS has been monitoring infiltration into disturbed and undisturbed sediments adjacent to the SDA since 1986 (Shakofsky, 1993; Pittman, 1989). The data gathered from the expanded network and the disturbed USGS location adjacent to the SDA have provided data to calibrate additional numerical models.

Figure 1. Location of the SDA.

1.3 Objectives

The main objective of this study was to model infiltration patterns at the SDA and estimate surficial sediment hydraulic parameters. This study is an extension of the NATs W02 and W06 infiltration study performed by Martian and Magnuson (1993). The calibration methodology used in that study was applied to the additional NATs in the expanded network. The results of the calibration simulations were then used to simulate infiltration during the entire operational period of the RWMC (1952-1995). These final simulation results will be used as a surface boundary condition in further subsurface pathway modeling efforts for the SDA Waste Area Group 7 baseline risk assessment and possibly future iterations of the RWMC Low Level Waste performance assessment.

Section 2 of this report contains descriptions of the simulated soil profiles for each NAT location and discusses the field monitoring program. Section 3 describes the numerical model used in the simulation study. Sections 4 and 5 discuss the calibration methodology and final simulations, respectively. Lastly, Section 5 presents the study conclusions and recommendations.

2. NAT DESCRIPTIONS

2.1 Geologic and Climatic Conditions

The SDA subsurface consists of a relatively thin layer of sediments composed of silt, sand, clay, and gravel near the surface ranging in thickness from 2 to 24 ft underlain by multiple basalt flows. Sedimentary interbeds occur infrequently in the sequence of basalt flows and range in thickness from a few feet to tens of feet. The basalt flows continue down to and through the aquifer, which is located approximately 120 m below the surface. These basalts are often fractured, especially near the top and bottom of each layer.

The climate on the INEL is that of a semi-arid, high desert region and is characterized by large daily and seasonal temperature variations. During the summer, low humidity, clear skies, and high temperatures result in high evaporation rates while average winter temperatures remain below freezing for 2 to 3 months, essentially preventing evapotranspiration during the winter. The average annual temperature is approximately 42 degrees F and, the average annual precipitation is 22 cm with 30% falling as snow (Clawson et al., 1989). Much of the precipitation occurs between the fall and late spring, with an occasional heavy thunderstorm occurring during the summer. Precipitation usually exceeds evaporation from October through May, and evaporation exceeds precipitation during June through September (Clawson et al., 1989).

2.2 NAT Descriptions

NATs W02 and W06 were installed in the fall of 1986. The neutron access holes were hand-augured to the underlying basalt at 14.5 ft and 10.5 ft below land surface for holes W02 and W06, respectively. Carbon steel pipes were then installed leaving 2 ft of pipe extending above the ground (Hubbell et al., 1987). In addition to the neutron access holes, three tensiometers were installed at 3-, 6-, and 9-ft depths in a borehole located approximately 4 ft east of NAT W06.

Between November 1993 and January 1994 15 additional NAT holes and four tensiometer holes were drilled in the SDA sediments. NATs 1, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 16, and 17 were completed through the surficial sediments to the underlying basalts. NATs 14 and 15 were installed in disturbed cover material over a closed waste pit and were completed to a depth of 6 ft. Geologic logs for these NATs can be found in McElroy (1993) and Bishop (1994). Figure 2 illustrates the RWMC moisture monitoring network at the end of September 1994.

Figure 2. SDA moisture monitoring network at the end of the 1994 fiscal year.

2.3 NAT Monitoring

In situ soil moisture and matric potential data at the NAT W02 and W06 locations were collected monthly from November 1986 to November 1990. In December 1992, neutron probe access tube monitoring was resumed with more frequent monitoring during the spring when the majority of infiltration occurred from snowmelt and spring rains. The NAT holes were monitored at least once a week prior to the spring snowmelt in March 1993, and monitored every other day during the snowmelt and subsequent infiltration in March and early April. As the soil profile began to dry, monitoring frequency was reduced to about once a week in April through June, bimonthly in July, and monthly during August and September (McElroy, 1993).

Frequent monitoring of the additional NATs began during the spring of 1994 and continued through 1995 on a less-frequent basis after most of moisture from spring snowmelt and rains had entered the soil. Frequent monitoring was again resumed during early 1995.

3. NUMERICAL MODEL

3.1 Infiltration and Redistribution Physics

Infiltration is the process by which surface water enters the soil. Redistribution is the process through which water made available from infiltration redistributes itself during infiltration and after the infiltration has stopped. After surface water has infiltrated into the soil, it redistributes itself in response to gravity and capillary forces. The redistribution process will ultimately partition the infiltrated water into a three-part water balance. These parts consist of (a) surface losses that are due to evaporation and transpiration, (b) drainage that becomes aquifer recharge, and (c) storage that remains in the vadose zone.

When water is applied in relatively small amounts, (i.e., at rates less than the soil's saturated conductivity), the water infiltrates as fast as it is applied, and the application rate controls the infiltration. However, as often is the case during spring snowmelt and summer thunder storms, application rates exceed the soil's infiltration capacity, and the soil's hydraulic conductivity controls the infiltration rate after the initial soil wetting. During the initial wetting, the infiltration rate can be very large and may even exceed the saturated hydraulic conductivity. This large initial infiltration rate is due to the extremely large matric potential gradients between the dry soil ahead of the wetting front and the moist soil behind the wetting front. Eventually, the infiltration rate will decrease with time because of pore infilling and eventually reach a steady-state rate near the soil's saturated hydraulic conductivity.

The partial differential equation governing unsaturated flow, including infiltration and redistribution, can be derived from the general mass conservation equation and Darcy's law as originally performed by Richards (1931).

3.2 Selected Model

The UNSAT-H Version 2.01 computer code (Fayer and Jones, 1990) was chosen for the simulations in this study because of its ability to model infiltration from meteorological conditions at semi-arid locations. Specifically, the code has the ability to account for (a) liquid and vapor water movement, (b) heat transfer by conduction and convection, (c) evaporation at the soil surface, and (d) transpiration by plants. The UNSAT-H code was verified and benchmarked by Baca and Magnuson (1990) and was successfully applied to simulate moisture transport at several semi-arid locations (Fayer et al., 1992; Baca et al., 1992; Magnuson, 1993; Martian and Magnuson, 1993).

3.2.1 General Description

The UNSAT-H model is designed to simulate the dynamics of water movement through the vadose zone as a function of meteorologic conditions and soil hydraulic properties. UNSAT-H Version 2.0 is an enhanced version of UNSAT-H 1.0. Version 1.0 simulates the processes of infiltration, redistribution, drainage, and evapotranspiration, and uses the potential evapotranspiration (PET) concept. Version 2.0 additionally includes options to calculate soil heat transfer coupled with water flow, surface-energy balance, and actual evaporation.

The model is written in FORTRAN 77 and consists of three main programs: (1) DATANH, a preprocessor, (2) UNSAT-H, the flow simulator, and (3) DATAOUT, a post-processor. For simple problems, the model runs efficiently on a personal computer. However, for complex soil profiles, the model requires a scientific workstation or larger computer.

3.2.2 Theoretical Background

The UNSAT-H model solves an extended, one-dimensional form of Richards' equation, which includes both liquid- and vapor-phase water movement. To model soil heat transfer, the model solves the advection/diffusion equation. The extended form of Richards' equation, as implemented in the model, is

$$C(h) \frac{\partial h}{\partial t} = \frac{\partial}{\partial z} \left[K_T(h) \frac{\partial h}{\partial z} + K_L(h) + q_{vT} \right] - S(z, t) \quad , \quad (1)$$

where

- z = depth
- h = total head
- S(z,t) = evapotranspiration sink term
- q_{vt} = thermal vapor flux density
- K_T = total hydraulic conductivity; K_T=K_L+K_{vh}
- K_L = liquid conductivity
- K_{vh} = isothermal vapor conductivity
- C(h) = slope of soil moisture curve; $\partial\theta/\partial h$.

The governing equations are solved using an iterative finite difference approximation with a Crank-Nicholson method for the time derivative. The finite difference technique replaces the partial derivatives with a quotient of two finite differences. The end result of using finite differences is that the partial differential equation is approximated by a series of algebraic equations that are solved simultaneously.

To solve Richards' equation, UNSAT-H requires parameterization of the moisture characteristic (C(h)) and hydraulic conductivity curves (K_L(h)). UNSAT-H contains four options for describing these soil hydraulic properties: polynomials, Haverkamp functions, Brooks-Corey functions, and van Genuchten functions.

UNSAT-H permits the user to select several boundary conditions. The lower boundary condition can be a unit gradient, constant head, specified flux, or zero flux. The upper boundary condition can be either a flux or a constant head. When the flux option is selected, the upper boundary condition is a function of meteorologic conditions and alternates between a flux and a constant head. Initially, during periods of infiltration or evaporation, the boundary is a flux. However, if the value at the surface node becomes less than a minimum suction head (saturated conditions) during infiltration, or if the surface node exceeds a maximum value (unnaturally dry conditions) during evaporation, the upper boundary becomes a constant head until conditions revert to normal. If the values of the surface node becomes less than a specified minimum, the minimum value can either be calculated internally from relative humidity or specified by the user.

Within UNSAT-H, evaporation is calculated either by an energy balance at the soil surface when the heat transfer option is selected or by the PET concept. PET is partitioned into potential transpiration (PT) and evaporation by one of two methods. The first method uses the leaf area index (LAI) to partition evaporation and transpiration by the equation

$$PT = PET[-0.21 + 0.70(LAI)^{1/2}] \quad (2)$$

where PET is the measured radiation and is not the PET calculated using the Penman method (Ritchie, 1972). In the second method, PET (net radiation) is partitioned into transpiration and evaporation using an empirical method posed by Hinds (1975) using data on cheatgrass growth.

The UNSAT-H model does not directly calculate runoff. However, if the flux of meteoric water into the surface exceeds the infiltration capacity, the excess water is assumed to be lost to runoff.

In order to solve Richards' equation, the UNSAT-H code must be supplied with the following four basic components: soil hydraulic properties, computational grid, initial conditions, and boundary conditions. Each of these components will be discussed in turn.

3.2.3 Hydraulic Properties

Characterizing unsaturated flow requires three basic hydraulic properties for each material type identified in the simulation profile. These three properties are (a) the moisture characteristic curve, which is the relationship between the matric potential and moisture content, (b) the hydraulic conductivity curve, which is the relationship between the matric potential and the unsaturated hydraulic conductivity, and (c) the saturated hydraulic conductivity. The van Genuchten equations were used to represent these constitutive relationships. The equation for the characteristic curve is

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{[1 + (\alpha h)^n]^{1 - \frac{1}{n}}} \quad (3)$$

where

- h = suction head
- θ = volumetric moisture content
- θ_r = residual moisture content
- θ_s = porosity
- n = pore-size distribution index
- α = inverse air-entry potential.

The equation for the hydraulic conductivity curve is

$$K(h) = K_s \frac{\{1 - (\alpha h)^{n-1} [1 + (\alpha h)^n]^{1 - 1/n}\}^2}{[1 + (\alpha h)^n]^{l(1 - 1/n)}} \quad (4)$$

where

- K(h) = unsaturated hydraulic conductivity
- K_s = saturated hydraulic conductivity
- l = pore interaction term.

Although obtaining soil hydraulic properties is one of the final objectives of this study, initial estimates of these properties were needed before beginning the calibration process. These initial estimates were obtained from the W02 and W06 calibration results. The geologic descriptions of the additional NAT holes were compared to the NAT W02 and W06 logs, and the hydraulic properties for similar layers were assigned.

3.2.4 Computational Grid

The general model domain is a one-dimensional vertical column. Soil layer profiles were constructed for the additional NATs by defining distinct soil layers and assigning hydraulic properties to each of the layers. Transition layers were then assigned between the main layers, and the hydraulic properties for these layers were linearly interpolated from the bounding layers.

Soil layering was determined by analyzing the neutron probe estimates of soil moisture profiles provided by McElroy (1993) and Bishop (1994). Low conductivity zones in soils typically have a higher moisture content because water tends to accumulate in these regions. This is primarily due to the restriction of water flow by the low conductivity zones and the higher capillarity in the finer pore spaces.

Finally, computational grids were assigned to the simulation profiles using exponentially decreasing and increasing spacing moving towards and away from soil type boundaries, respectively. Exponential spacing at material interfaces places more nodes in areas where they are needed (i.e., at high-gradient areas at the surface due to evaporation or infiltration and high-gradient areas across interfaces due to different material types). The end result is to reduce pressure gradients across adjacent nodes and provide a more accurate solution. The extent of layering and the depth of each layer was adjusted in the calibration process.

3.2.5 Initial Conditions

For calibrating the simulations to the 1994-1995 NAT data, initial matric potentials in the profile layers were directly estimated from the neutron probe measurements of moisture content. As the soil properties were adjusted during the calibration process, a new estimate of initial matric potential was calculated.

The method used in this modeling study to obtain initial conditions for the final 1952-1995 simulations was to select a time far enough in advance of the simulation period of interest so that the water profile in the surficial sediments would be in equilibrium with meteorologic conditions when the simulation period of interest occurred. The starting time that was chosen for this purpose was January 1, 1950. This starting time allowed two years as a buffer for this equilibrium to occur. For these final simulations, the 1994 moisture contents were used for the first year of the simulation (1950).

3.2.6 Boundary Conditions

The lower boundary condition was specified as a unit gradient (water movement across the bottom boundary layer is only influenced by gravity). The upper boundary, as implemented in the UNSAT-H code, can be either a flux or constant head as discussed in Section 3.2.2.

The UNSAT-H code requires daily records of meteorologic data in order to compute the upper boundary condition. These parameters are maximum and minimum air temperature, dewpoint temperature, solar radiation, average wind speed, average cloud cover, and daily precipitation. However, the cloud cover information is used only to calculate radiative heat losses at the soil surface when the heat transfer option has been selected.

The meteorologic data base from the W02 and W06 calibration study was extended forward through April 1995 and backward to January 1950. Most of weather data used to extend the meteorologic database were obtained from the National Oceanographic and Atmospheric Administration (NOAA) weather station located at the Central Facilities Area (CFA). However, solar radiation, cloud cover, and dewpoint information was not available from CFA. Also, there were missing periods of average wind speed in the CFA weather data. The average wind speed for the periods 1950-1954 and 1971-1981 and the dewpoint data were obtained from the NOAA weather station located at the Pocatello airport. Magnuson (1993) found a good correlation between weather parameters measured at the Pocatello airport and at the CFA.

The missing solar radiation data were synthetically generated using the WGEN computer program (Richardson and Wright, 1984). WGEN allows the synthetic data to be conditioned on observed precipitation and temperatures. Magnuson (1993) showed a high correlation between synthetic values generated with WGEN and measured values at a United States Geological Survey weather station adjacent to the SDA. The missing cloud cover information was not necessary because the UNSAT-H heat transfer option was not used.

Because the daily precipitation records collected at the NOAA weather station included all forms of precipitation including both rain and snow, the precipitation amounts were modified during the winter months to account for snow accumulation and melting following the method outlined in Magnuson (1993). The results of this modification were to concentrate winter precipitation into a short period of snowmelt each spring.

When the ground surface is covered with snow, the snow prevents most evaporation from occurring by insulating the ground from wind and solar radiation. Additionally, as the ground freezes, the effective porosity and hydraulic conductivity can be reduced by any remaining moisture freezing in the soil pores. This reduces evaporation by limiting the amount of soil water that can move toward the soil surface. Finally, most vegetation becomes dormant during the winter months, further decreasing evapotranspiration. The combination of the above processes effectively stops most evapotranspiration during the winter season. To accurately simulate winter soil processes, the potential evapotranspiration was set to zero during the winter period.

The criteria for selecting the start of the winter period was the beginning of the first extended period in which the average temperature fell below freezing where the average temperature was the average of the maximum and minimum values. Conversely, the criteria for selecting the last day of the winter period was the day preceding the first period in which the average temperature was above freezing.

Results of calibration simulations showed better agreement with field measurements when the no evapotranspiration period was extended two weeks beyond the winter period discussed above. The final simulations were run using the extended period of zero evapotranspiration. Physically, extending the zero evapotranspiration two weeks each winter matches the actual conditions in the soil because the ground may remain frozen a short period after average temperatures rise above freezing. Table 1 lists the periods when the potential was not set to zero for each simulation year.

Table 1. Period of non-zero evapotranspiration by calendar year.

Year	First day	Last day	Year	First day	Last day
1950	69	313	1973	107	324
1951	92	307	1974	74	328
1952	110	307	1975	92	346
1953	23	322	1976	72	332
1954	42	331	1977	82	323
1955	84	314	1978	93	316
1956	92	302	1979	91	317
1957	67	311	1980	64	320
1958	61	315	1981	62	327
1959	73	317	1982	60	314
1960	96	309	1983	71	323
1961	52	316	1984	88	320
1962	98	320	1985	105	312
1963	46	320	1986	60	311
1964	105	316	1987	75	319
1965	43	328	1988	71	316
1966	80	338	1989	80	329
1967	57	325	1990	74	330
1968	64	318	1991	58	300
1969	100	320	1992	53	324
1970	56	318	1993	97	340
1971	83	318	1994	70	305
1972	72	302	1995	81	

4. MODEL CALIBRATION

Model calibration is the trial-and-error process of adjusting input data until computed data match the field observations. This calibration included adjusting the soil hydraulic parameters, the soil layering, and timing and amount of spring snowmelt. The initial estimates of soil layering and hydraulic parameters discussed in Sections 3.2.3 and 3.2.4 were adjusted until a reasonable match between field measurements and simulation moisture contents were obtained.

4.1 Evaluation Criteria

The moisture contents from the neutron probe measurements were used to evaluate how well the numerical model approximated the conditions in the field for each NAT simulated. The tensiometer field measurements of matric potential taken near NATs 6, 7, 11, 12, 14, and 16 were not rigorously used to calibrate the models because the data tended to be somewhat erratic.

Evaluating the match between simulated and field moisture contents required both quantitative and qualitative criteria. Two quantitative indicators were chosen to measure the agreement between field data and simulation results. The first indicator was the root mean square (RMS) error; the second was the correlation coefficient.

The RMS error provides a good estimation of the average error throughout the two data sets and is defined by the equation

$$RMS = \frac{\sqrt{\sum_{i=1}^k (s_i - f_i)^2}}{k} \quad (5)$$

where

- f_i = field data point
- s_i = simulation data point
- k = number of comparison points.

The correlation coefficient measures the degree to which there is a linear correlation between corresponding field data and simulation results. It provides an estimate of how well the trends between the data sets agree (i.e., the shape of the data curve). The correlation coefficient is defined by the quantity

$$r = \frac{k \sum_{i=1}^k s_i f_i - \sum_{i=1}^k s_i \sum_{i=1}^k f_i}{\sqrt{\left[k \sum_{i=1}^k s_i^2 - \left(\sum_{i=1}^k s_i \right)^2 \right] \left[k \sum_{i=1}^k f_i^2 - \left(\sum_{i=1}^k f_i \right)^2 \right]}} \quad (6)$$

A perfectly linear relationship between data sets would result in a correlation coefficient of 1. At the other end of the scale, a correlation coefficient of 0 indicates that no correlation exists and the data sets are completely independent.

Finally, graphical comparisons between the measured and simulated data were used to qualitatively judge how well the simulation results matched field moisture content data. Plots were made of the measured data superimposed on the simulation results, and the agreement was visually evaluated.

4.2 Calibration Parameters and Methods

The UNSAT-H input parameters that were adjusted in the calibration process were (1) porosity, (2) residual moisture content, (3) inverse air-entry potential, (4) pore size distribution index, and (5) saturated hydraulic conductivity. The amount and timing of spring snowmelt occurring at each NAT location was also adjusted. Results of the neutron probe moisture monitoring performed during 1994 and 1995 were used to adjust the parameters listed above for each NAT location.

The variability in infiltration amounts seen in the neutron probe measurements occurring across the SDA is primarily influenced by the local topography around each NAT. Redistribution of melting snow can occur during years with frozen ground, a substantial snow pack, and a short snow melt period. The spring infiltration patterns that occurred during 1994 and 1995 may represent the extremes for a small amount and a large amount of redistribution, respectively.

To estimate the amount and timing of water which infiltrated at each location during the spring of 1994 and 1995, the net amount of water which entered the ground at each NAT location was roughly calculated by summing the differences in neutron probe moisture contents between each monitored date using the equation

$$I = \sum_{t=1}^{t=t_f} 6(\theta_{t+1} - \theta_t) \quad (7)$$

where

I = net infiltrated water within the profile

θ = moisture content

t = times at which field measurements were taken

6 = distance between moisture content measurements (in).

The maximum estimated infiltration amount and the date on which it occurred were retained from the differencing along with the period over which it occurred. These amounts resulted in either an excess or deficit of infiltrated water relative to the cumulative amount of precipitation that occurred during the preceding winter. These amounts were then added or subtracted from the meteorologic records input into the numerical model. Initial estimates for period over which the meteorological records were modified was also determined from the differencing. The starting date was the date the net infiltrated water became positive, and the ending date was the date of maximum infiltration.

It is important to note that steady-state drainage cannot be accounted for using this method, and the actual infiltration amounts could have been higher. Results of the differencing for each NAT location for the years 1994 and 1995 are presented in Tables 2 and 3, respectively.

Table 2. 1994 SDA infiltration estimates.

NAT	Julian day of maximum infiltration	Infiltration period (Julian day)	Maximum infiltration amount (in.)
1	74	57-74	0.22
2	66	57-74	3.81

Table 2. 1994 SDA infiltration estimates.

NAT	Julian day of maximum infiltration	Infiltration period (Julian day)	Maximum infiltration amount (in.)
3	74	57-74	0.20
4	74	57-74	0.51
5	74	57-74	1.18
6	74	57-74	3.84
7	74	57-74	0.04
8	72	57-74	1.66
9	74	57-74	0.20
10	74	57-74	-0.86
11	74	57-74	0.61
12	87	57-74	2.84
13	66	57-74	5.49
14	74	57-74	0.08
15	63	57-74	1.43
16	74	57-74	0.15

Table 3. 1995 SDA infiltration estimates.

NAT	Julian day of maximum infiltration	Infiltration period (Julian day)	Maximum infiltration amount (in.)
1	93	51-93	1.12
2	51	39-51	5.09
3	86	51-86	0.89
4	58	9-58	-0.48
5	58	39-58	2.32
6	51	39-51	18.3
7	86	51-86	1.55
8	100	51-100	3.25
9	86	51-86	0.92
10	86	51-86	1.62
11	58	39-58	14.5
12	58	39-51	20.6
13	72	51-72	15.9

Table 3. 1995 SDA infiltration estimates.

NAT	Julian day of maximum infiltration	Infiltration period (Julian day)	Maximum infiltration amount (in.)
14	86	51-86	0.37
15	100	51-89	0.84
16	72	51-72	9.19

4.3 Calibration Results

The moisture content profiles obtained from the final calibration simulations generally showed good agreement with the field moisture content measurements. The average correlation coefficient between the simulation moisture contents and the field measurements varied between 0.95 for NAT 5 and 0.34 for USGS-15. The average correlation coefficient for all NATs was 0.803. The RMS error varied between 0.012 for NAT 5 and 0.065 for NAT 12. The average RMS error for all NATs was 0.03. This average RMS error corresponds to roughly a ten percent error and the average correlation coefficient indicates that there is a strong correlation between field measurements and simulated moisture contents. Because field measurements of matric potential were not consistent throughout the calibration periods, an attempt was made to obtain only a rough order of magnitude agreement with field matric potentials.

Graphical comparisons of model and field moisture contents are illustrated in Figures 3 through 8. A spring and winter time point are illustrated for each calibration year for each NAT location. The spring date was selected to illustrate how well the models simulated infiltration from snowmelt. The models did a fairly good job in capturing the timing and magnitude of the spring infiltration events but tend to predict slightly faster than observed drying trends following the spring infiltration events. Figures 3 through 8 do not illustrate these drying trends because only the infiltration peak is presented for 1994 and 1995. The final hydraulic properties and soil layering for each NAT location obtained from the calibration exercise are provided in Appendix A.

The calibration simulations for NATs 2 and 6 are a limited validation of the calibration methodology used in Martian and Magnuson (1993) as well as this study. The soil hydraulic properties for these two locations were those obtained from Martian and Magnuson (1993). The validation is limited because the water application amounts and timing from spring snowmelt were obtained from the integration of the 1994 and 1995 SDA moisture monitoring data discussed in Section 4.2. The NAT 6 simulations show very good agreement with the 1994 and 1995 soil moisture monitoring data while the NAT 2 simulations show good agreement with the 1994 data but predict an early rise in moisture content during the 1995 spring infiltration event. Because NAT 2 was removed from the monitoring network in February, the entire spring infiltration event was not recorded, and a complete comparison of field data and simulation data is not possible.

Calibration of soil hydraulic properties for NATs 14 and 15, and the USGS NAT-15 locations was obtained with adjusting the meteorological records to account for redistribution of melting snow. This was because the field moisture contents were only recorded in the uppermost 6 to 8 ft of the sediments and may be one of the reasons only a fair match between observed and simulated moisture contents was obtained for the USGS NAT-15 location.

Figure 3. Calibration results for NATs 1, 2, and 3. (Simulated moisture contents are dashed lines and field moisture contents are solid lines.)

Figure 4. Calibration results for NATs 4, 5, and 6. (Simulated moisture contents are dashed lines and field moisture contents are solid lines.)

Figure 5. Calibration results for NATs 7, 8, and 9. (Simulated moisture contents are dashed lines and field moisture contents are solid lines.)

Figure 6. Calibration results for NATs 10, 11, and 12. (Simulated moisture contents are dashed lines and field moisture contents are solid lines.)

Figure 7. Calibration results for NATs 14, 15, and 16. (Simulated moisture contents are dashed lines and field moisture contents are solid lines.)

Figure 8. Calibration results for NAT 16 and USGS-15. (Simulated moisture contents are dashed lines and field moisture contents are solid lines.)

5. FINAL SIMULATIONS

5.1 Simulation Methods

To perform the infiltration simulations for the operational period of the SDA, it was necessary to estimate the amount of surface water redistribution that may have occurred at each NAT location for each simulation year. The spring infiltration patterns observed during 1994 and 1995, along with the weather patterns that were responsible for creating these conditions, were used to estimate spring infiltration for each year.

As discussed in Section 4.1.1, the years 1994 and 1995 had very different infiltration behavior at each of the NATs. A large amount of redistribution occurred during 1995 while very little occurred 1994. The primary cause for the large amount of redistribution that occurred during 1995 was deeply frozen soil and a rapid early snowmelt during the spring. The winter of 1995 had long periods of very cold temperatures with little snow cover to insulate the soil and a rapid transition from winter to spring temperatures. The end effect of these conditions were to redistribute the melt water to low areas in the SDA before the water could percolate into the ground.

The weather records for each simulation year were reviewed and the spring infiltration pattern for each simulation year was classified into one of three categories.

- *Category I:* A long protracted snowmelt with no redistribution via surface or near surface flow.
- *Category II:* An intermediate snowmelt period over soil that is not deeply frozen, permitting only a limited amount of redistribution. These are conditions similar to the spring of 1994.
- *Category III:* A rapid snowmelt over deeply frozen soil, permitting a large amount of redistribution. These are conditions similar to the spring of 1995.

The infiltration categories were determined by analyzing the meteorological records for each simulation year. Three criteria were used to determine which infiltration category each year was classified into. These were (1) the number of winter days with a snow cover, (2) the amount of water equivalent in the snow cover during the spring snowmelt, and (3) the number of days of the spring snowmelt. The algorithm that was used to modify the precipitation records during the winter (Section 3.2.6) was also used to estimate selection criteria.

To determine the amount of water that was applied each spring from snowmelt, multiplication factors were determined for the cumulative winter precipitation. The infiltration amounts were obtained from the differencing of field moisture contents as discussed in Section 4.2, and the cumulative winter precipitation was determined by summing all precipitation that occurred during the winter period discussed in section 3.2.6 minus the two weeks each spring for soil thawing. Table 4 presents the multiplication factors for each NAT location for 1994 and 1995. Table 5 presents each simulation year, the total winter precipitation, and the infiltration category.

Table 4. Winter precipitation infiltration multiplications factors for 1994 and 1995.

NAT	1994	1995
	Multiplication factor	Multiplication factor
1	0.20	1.39
2	3.55	6.28
3	0.18	1.10
4	0.46	-0.59
5	1.07	2.86
6	3.49	22.6
7	0.03	1.91
8	1.50	4.01
9	0.18	1.13
10	-0.78	2.00
11	0.55	17.9
12	2.60	25.4
13	4.99	19.7
16	0.14	11.34

Table 5. Winter precipitation totals and simulation category for each simulation year.

Year	Winter Precipitation Total	Infiltration Category	Year	Winter Precipitation Total	Infiltration Category
1950		I	1973	4.09	II
1951	2.35	III	1974	2.26	I
1952	3.11	II	1975	3.03	II
1953	1.17	III	1976	0.99	I
1954	0.81	I	1977	0.96	II
1955	1.08	II	1978	4.15	II
1956	3.68	III	1979	3.02	II
1957	2.11	III	1980	1.52	III
1958	2.04	II	1981	1.60	II
1959	1.33	I	1982	1.92	II
1960	3.60	III	1983	2.70	II
1961	1.55	II	1984	1.90	I
1962	4.56	III	1985	3.31	II
1963	1.32	II	1986	2.36	III
1964	2.46	II	1987	1.22	III
1965	6.27	I	1988	0.94	II
1966	1.34	III	1989	3.10	I
1967	1.84	I	1990	1.69	III
1968	1.56	I	1991	0.41	II
1969	5.06	II	1992	0.96	II
1970	1.14	II	1993	3.55	II
1971	3.36	I	1994	1.1	II
1972	2.88	III	1995	0.81	III

The precipitation records used in each simulation for the period 1952-1995 were modified to match the estimated infiltration amounts that occurred at each NAT for each simulation year. The difference between the total estimated infiltration (i.e., total winter precipitation $\times$ the multiplication factor, category I = no change, category II = 1994 factor, category III = 1995 factor) and the total winter precipitation was either added or subtracted from the water equivalent snowpack in the precipitation input files.

5.2 Simulation Results

The simulation results for the 1952-1995 simulation period indicate that spring infiltration events from snowmelt and rainfall dominate the flow patterns within the SDA surficial sediments. Almost complete dampening of low-magnitude infiltration events occurs in the surficial sediments. However, high-magnitude infiltration events persist as discrete events down to the basalt interface. This can be seen in Figures 9 through 11, which illustrate the water flux across four depths at NATs 7, 4, and 12, respectively. These NATs represent locations with ambient, low, and high infiltration rates, respectively. Furthermore, NAT locations with more homogeneous lithology experienced the most damping (i.e., NATs 9, 14, 15, and USGS-15). The daily flux rates

in graphical form and the annual flux totals entering the basalts for each simulation location are provided in Appendix B.

The amount of water that moves beyond the basalt interface is a good estimate of recharge because this water has no chance of returning to the surface via evapotranspiration. This is primarily due to the depth of the interface and the different soil moisture characteristics between the sediments and the basalts. The basalts typically retain much less water and have lower unsaturated conductivities than the sediments at the same tension and do not permit an upwards gradient to the sediments.

The average annual drainage into the basalts at each NAT location averaged over the simulation period is presented in Table 6. The values ranged from 0.64 cm for NAT 4 to 41.9 cm for NAT 6. The average yearly drainage for all NATs simulated was 10.0 cm. This value represents approximately 48 percent of the total annual precipitation and is significantly higher than the recharge estimates performed by other researchers at the INEL. This high recharge estimate can be partly explained by the physical setting of the SDA. The SDA resides in a shallow basin that may encourage accumulation of drifting snow. Furthermore, many of the NATs are located in low areas at the SDA that may have higher localized recharge rates.

The recharge rates predicted by NATs 3, 4, 5, 7, 8, 9, and 16 may provide a better prediction of the average recharge over SDA. This location represents a somewhat level area within the SDA, and the NATs include soil profiles with and without the coarse sand layers, which may affect infiltration by functioning similar to a capillary barrier. The average yearly drainage into the basalts from these simulations was 6.5 cm, which is approximately 31 percent of the average total precipitation.

Figure 9. NAT 7 simulation daily flux values (representative of an average infiltration rate).

Figure 10. NAT 4 simulation daily flux values (representative of a low infiltration rate).

Figure 11. NAT 12 simulation daily flux values (representative of a high infiltration rate).

Table 6. Simulation average annual drainage into basalt

NAT	Average annual drainage (cm)	NAT	Average annual drainage (cm)
1	1.35	10	0.69
2	11.4	11	10.1
3	1.37	12	27.5
4	0.64	13	24.1
5	5.82	14	2.40
6	41.9	15	0.65
7	5.11	16	23.8
8	3.68	USGS-15	5.78
9	5.29	Average	10.0

The simulation results were also used to estimate the evaporative depth at each of the NAT locations. This depth was determined by finding the lowest depth in each profile that had an upwards flux greater than 10^{-4} cm/day for each simulation day for the years 1963, 1990, and 1976. These years were chosen to capture the variation in extremes in evaporative depth. The year 1963 represents a wet year that was preceded by several wet years, and 1990 represents a dry year that was preceded by several dry years. The year 1976 represents a year with average precipitation. Table 7 lists each NAT and the maximum evaporative depths at that location. Figure 12 presents the daily evaporative depth for NAT 9. This figure illustrates how the evaporative depth can vary significantly from day to day depending on the magnitude of precipitation events. Appendix C contains the daily evaporative depth for each NAT location for 1963, 1990, and 1976.

Table 7. Maximum simulation evaporative depths for 1976.

NAT	Evaporative depth (in.)	NAT	Evaporative depth (in.)
1	29	10	38
2	59	11	101
3	36	12	77
4	25	13	82
5	41	14	101
6	105	15	136
7	27	16	26
8	100	USGS-15	25
9	17		

The evaporative depth predicted by the NAT W06 model compares favorably with field monitoring of soil tensions performed by McElroy (1993). Results of the field monitoring indicated that an upward gradient can extend to the 6- to 9-ft depth in late July near NAT 6. Simulation results for NAT 6 indicated that a maximum evaporative depth of 8.75 ft was achieved in August of 1990 and 1994.

Figure 12. NAT 9 daily evaporative for 1963, 1990, and 1994.

5.3 SDA Areal Infiltration Model Source Term

To facilitate using the infiltration rates obtained from this study in the WAG 7 baseline risk assessment SDA subsurface flow model, the daily infiltration records from the final simulations were interpolated and assigned to different areas across the SDA. Infiltration rates from three of the NAT infiltration models were chosen to represent three different infiltration rates for the SDA. A low, medium, and high infiltration rate was assumed to be minimum number of infiltration rates needed to represent the varying infiltration rates across the SDA.

The locations of NATs 4, 8, and 13 were selected to represent the low, medium, and high rates of infiltration, respectively. The infiltration rates are the daily flux rates at the 75-cm depth. The 75-cm depth was chosen because the flux was primarily downwards at this depth, and the selected depth was shallow enough to represent a flux rate above the emplaced waste.

To determine the areal distribution of these infiltration rates, an attempt was made to correlate the local topography and lithology with the varying infiltration rates. Topographic influences were found to overshadow any effects that the varying lithology may have on infiltration. Therefore, the SDA topography was primarily used to distribute the three flux rates across the SDA. The following three sources of information were used to estimate the areal distribution of the low, medium and high infiltration rates: (1) the locations of ponded water which occurred during February 1995, (2) the annual average infiltration rates for each NAT estimated from this modeling study, and (3) the current SDA topography.

The observed locations of significant ponded water were reported by Bishop (1995) and are illustrated in Figure 13. These areas of ponded water were used to identify high infiltration rates, and adjacent areas of higher elevation were used to identify areas of low infiltration. The SDA surface topography was also contoured, and a plane at 5,013-ft was superimposed on the contour map. The relative differences between the plane and the SDA surface elevation was used to identify local catchments where snowmelt would accumulate and result in higher infiltration rates. The SDA surface contour map illustrating the relative elevation differences with a 5,013-ft datum is provided in Figure 14 along with the areal distribution of average annual infiltration rates determined from the final simulations. The contours in Figures 13 and 14 are not labeled because the intent of both figures is to simply present areas where snowmelt may accumulate.

Figure 13. Observed locations of ponded water during February 1995 (from Bishop, 1995)

Figure 14. SDA average annual infiltration rates and surface elevation departure from 5013 ft datum.

The SDA surface was discretized using the coarsest grid blocks possible, which would still retain adequate resolution for the purposes of assigning the different infiltration rates. The average infiltration rate over the entire SDA resulting from the areal interpolation was 8.5 cm/yr. This value falls between the possible ranges of average infiltration predicted by the modeling discussed in Section 5. This value is felt to

be appropriate because a large percentage of the infiltration that occurs at the SDA is a result of spring snowmelt, and the local topography of the SDA may encourage snow accumulation. Figure 15 illustrates the infiltration rate distribution interpreted for the SDA.

Figure 15. Infiltration rate distribution for water source term model.

Because the infiltration rates resulting from the NAT 4, 8 and 13 simulations consisted of daily records for the entire 45-year simulation, the data were lumped into abbreviated data sets. The abbreviated data sets used varying time periods for the different flux rates. The largest possible time periods were used which still captured the transient nature of the infiltration rates.

To accomplish this task, an upper background infiltration rate was chosen along with a range of variability for any single time period. If the daily infiltration rate was below the background limit, an average of all rates below this limit was assigned for that time. If the daily infiltration rate was above the background limit and within the specified range, the infiltration rate was the average of the all the rates that fell within the range.

The end result of the process was to significantly reduce the total number of data points needed to describe the transient nature of the data while keeping the total amount of water determined by the flux rates the same. The differences between the amount of water applied between from the abbreviated and original data sets were 0.02, 0.19, and 0.06 percent for the low, medium and high flux rates, respectively. Plots of the daily and abbreviated infiltration data versus time are presented Figures 16 through 18. The plots illustrate that the large infiltration pulses that occur each spring are maintained in the abbreviated data sets. These data sets describe time and areal variant infiltration rates for use in the WAG 7 Baseline Risk Assessment. The data in tabular form are included in Appendix D.

Figure 16. Original and abbreviated infiltration data representing the low infiltration rate.

Figure 17. Original and abbreviated infiltration data representing the medium infiltration rate.

Figure 18. Original and abbreviated infiltration data representing the high infiltration rate.

6. CONCLUSIONS AND RECOMMENDATIONS

The simulation results confirm previous opinions that spring infiltration events from melting snow and rain account for a large proportion of the recharge occurring beneath the SDA and that only a limited amount of dampening of these flux rates occurs in the surficial sediments. The results also suggest that the average annual recharge may be approximately 6.5 cm/yr and could be as high as 10 cm/yr. Both these values are larger than the average annual winter precipitation over the simulation period which was of approximately 6 cm. These high recharge estimates imply the local topography of the SDA (i.e. dikes and fences) may encourage drifting snow to accumulate within the SDA.

The task of interpolating the simulation infiltration rates across the SDA suggested that topographic influences have the largest effect on varying infiltration rates at the SDA and may overshadow any lithologic influences.

The snowpack amounts and snowmelt timing along with the subsequent redistribution, are the largest sources of uncertainty encountered in the modeling study. Accurate measurements of winter snowpack within and outside the SDA are needed to validate these high recharge estimates. If water-equivalent measurements of snowpack for years in which a snowpack develop are consistent with the cumulative recharge amounts, the high estimates would be justified.

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Appendix A

Model Hydraulic Properties

Appendix A

Model Hydraulic Properties

This appendix contains the soil hydraulic properties for each NAT location obtained from the calibration exercises. The hydraulic properties presented in table A-1 consist of profile layering and the van Genuchten parameters to represent the moisture characteristic and the unsaturated hydraulic conductivity curves.

Table A-1. NAT model hydraulic properties.

Soil Layer	Layer Bottom (cm)	K _s (cm/hr)	Porosity	Residual	Alpha (1/cm)	n
NAT 1						
1	26.000	.250	.500	.100	.012	1.920
2	45.700	.900	.500	.100	.018	1.920
3	60.900	2.267	.503	.100	.045	1.810
4	76.200	3.633	.507	.100	.073	1.700
5	91.440	5.000	.510	.100	.100	1.590
6	106.700	5.000	.510	.100	.092	1.590
7	137.200	5.000	.510	.100	.084	1.590
8	152.400	6.650	.532	.069	.057	1.695
9	167.600	11.400	.554	.038	.030	1.800
10	190.500	15.633	.516	.038	.033	2.050
11	213.400	19.867	.478	.038	.037	2.300
12	228.600	24.100	.440	.038	.040	2.550
13	251.500	19.867	.478	.038	.053	2.300
14	274.300	15.633	.516	.038	.065	2.050
15	311.200	11.400	.554	.038	.078	1.800
16	511.200	1.000	.230	.015	.038	1.474
NAT 3						
1	30.480	2.000	.510	.120	.023	1.590
2	43.340	2.500	.500	.140	.050	1.650
3	68.580	12.500	.510	.120	.120	1.590
4	89.000	10.000	.507	.127	.073	1.610
5	104.730	7.500	.503	.133	.047	1.630
6	119.540	5.000	.500	.140	.020	1.650
7	152.400	8.750	.505	.130	.025	1.620
8	195.000	12.500	.510	.120	.030	1.590
9	220.000	8.250	.505	.130	.065	1.620

Table A-1. NAT model hydraulic properties.

Soil Layer	Layer Bottom (cm)	K _s (cm/hr)	Porosity	Residual	Alpha (1/cm)	n
10	239.880	4.000	.500	.140	.100	1.650
11	243.840	4.000	.500	.140	.100	1.650
12	259.080	4.000	.500	.140	.100	1.650
13	274.320	10.700	.480	.106	.080	1.950
14	284.500	17.400	.460	.072	.060	2.250
15	310.040	24.100	.440	.038	.040	2.550
16	350.040	1.300	.230	.015	.038	1.474
NAT 4						
1	38.100	5.000	.510	.120	.026	1.590
2	53.340	8.750	.510	.120	.093	1.510
3	68.580	12.500	.510	.120	.160	1.430
4	83.820	12.500	.510	.120	.109	1.510
5	99.060	12.500	.510	.120	.059	1.590
6	114.300	12.500	.510	.120	.055	1.590
7	144.780	12.500	.510	.120	.045	1.590
8	160.020	12.500	.510	.120	.034	1.590
9	182.880	8.750	.505	.130	.035	1.620
10	198.120	5.000	.500	.140	.035	1.650
11	205.740	8.750	.505	.130	.037	1.620
12	216.410	12.500	.510	.120	.039	1.590
13	248.500	12.500	.510	.120	.035	1.590
14	281.940	12.500	.510	.120	.060	1.590
15	481.940	1.000	.230	.015	.038	1.474
NAT 5						
1	60.960	12.500	.510	.120	.026	1.590
2	91.440	5.000	.500	.140	.037	1.650
3	106.680	.900	.500	.060	.020	1.600
4	121.920	6.700	.505	.090	.025	1.595
5	213.360	12.500	.510	.120	.030	1.590
6	243.840	8.750	.505	.130	.033	1.620
7	304.800	5.000	.500	.140	.035	1.650
8	326.130	12.500	.510	.120	.033	1.590
9	350.520	12.500	.510	.120	.026	1.590
10	381.000	10.000	.507	.127	.022	1.610

Table A-1. NAT model hydraulic properties.

Soil Layer	Layer Bottom (cm)	K _s (cm/hr)	Porosity	Residual	Alpha (1/cm)	n
11	400.810	7.500	.503	.133	.019	1.630
12	420.620	5.000	.500	.140	.015	1.650
13	495.300	8.750	.505	.130	.021	1.620
14	518.160	12.500	.510	.120	.026	1.590
15	579.120	1.000	.230	.015	.038	1.474
NAT 7						
1	45.720	3.000	.510	.120	.021	1.590
2	91.440	8.000	.510	.120	.031	1.590
3	137.160	8.100	.518	.104	.023	1.658
4	167.640	8.200	.527	.089	.015	1.725
5	217.930	10.350	.518	.104	.020	1.658
6	237.740	12.500	.510	.120	.026	1.590
7	298.700	10.000	.507	.127	.022	1.610
8	350.520	7.500	.503	.133	.018	1.630
9	377.950	5.000	.500	.140	.014	1.650
10	393.190	3.000	.505	.130	.014	1.620
11	434.340	1.000	.510	.120	.015	1.590
12	454.150	6.750	.510	.120	.021	1.590
13	491.340	12.500	.510	.120	.026	1.590
14	691.340	1.000	.230	.015	.038	1.474
NAT 8						
1	30.480	.720	.500	.060	.010	1.600
2	76.200	2.860	.500	.090	.023	1.595
3	96.010	5.000	.500	.120	.035	1.590
4	121.920	5.000	.500	.130	.022	1.620
5	158.500	5.000	.500	.140	.009	1.650
6	190.500	3.450	.505	.130	.016	1.620
7	216.400	1.900	.510	.120	.023	1.590
8	251.460	9.300	.487	.093	.031	1.910
9	271.270	16.700	.463	.065	.040	2.230
10	286.500	24.100	.440	.038	.048	2.550
11	353.570	16.267	.460	.072	.033	2.227
12	381.000	8.433	.480	.106	.019	1.903
13	406.910	.600	.500	.140	.004	1.580

Table A-1. NAT model hydraulic properties.

Soil Layer	Layer Bottom (cm)	K _s (cm/hr)	Porosity	Residual	Alpha (1/cm)	n
14	502.920	.800	.505	.130	.007	1.585
15	548.640	1.000	.510	.120	.010	1.590
16	565.400	.800	.505	.130	.010	1.585
17	579.120	.600	.500	.140	.010	1.580
18	607.160	1.000	.230	.015	.038	1.474
NAT 9						
1	67.060	3.500	.510	.120	.026	1.590
2	134.110	12.500	.510	.120	.026	1.590
3	190.500	8.750	.505	.130	.019	1.620
4	213.360	5.000	.500	.140	.012	1.650
5	243.840	5.000	.500	.140	.012	1.650
6	320.040	8.750	.505	.130	.021	1.620
7	441.960	5.000	.500	.140	.016	1.650
8	487.680	3.000	.505	.130	.013	1.620
9	530.350	1.000	.510	.120	.009	1.590
10	554.740	6.750	.510	.120	.022	1.590
11	579.120	12.500	.510	.120	.034	1.590
12	647.700	6.750	.510	.120	.026	1.590
13	678.180	1.000	.510	.120	.018	1.590
14	746.760	1.000	.230	.015	.038	1.474
NAT 10						
1	15.000	.150	.500	.060	.010	1.600
2	32.860	.150	.500	.060	.015	1.600
3	65.000	.610	.500	.060	.031	1.600
4	70.000	5.000	.500	.140	.019	1.650
5	76.200	5.000	.500	.140	.017	1.650
6	100.000	5.000	.500	.140	.016	1.650
7	111.000	5.000	.503	.127	.041	1.630
8	121.920	5.000	.507	.113	.065	1.610
9	137.160	5.000	.510	.100	.090	1.590
10	152.400	5.000	.505	.120	.073	1.620
11	190.000	5.000	.500	.140	.057	1.650
12	213.360	11.367	.480	.106	.051	1.950
13	243.840	17.733	.460	.072	.046	2.250

Table A-1. NAT model hydraulic properties.

Soil Layer	Layer Bottom (cm)	K _s (cm/hr)	Porosity	Residual	Alpha (1/cm)	n
14	308.460	24.100	.440	.038	.040	2.550
15	508.460	1.000	.230	.015	.038	1.474
NAT 11						
1	30.480	.400	.500	.060	.010	1.600
2	45.920	.450	.500	.060	.011	1.600
3	67.060	.450	.500	.060	.011	1.600
4	82.300	.450	.500	.060	.011	1.600
5	121.920	3.225	.505	.090	.021	1.595
6	155.500	6.000	.510	.120	.030	1.590
7	188.980	4.833	.507	.127	.024	1.610
8	225.550	3.667	.503	.133	.018	1.630
9	243.840	2.500	.500	.140	.012	1.650
10	289.560	1.400	.500	.140	.009	1.615
11	345.340	.300	.500	.140	.005	1.580
12	545.340	.400	.230	.015	.038	1.474
NAT 12						
1	38.100	1.800	.410	.060	.009	1.600
2	60.960	1.800	.410	.060	.009	1.600
3	112.780	1.400	.410	.100	.019	1.625
4	152.400	1.000	.410	.140	.030	1.650
5	167.640	8.700	.420	.106	.037	1.950
6	182.880	16.400	.430	.072	.045	2.250
7	259.100	24.100	.440	.038	.052	2.550
8	281.940	16.867	.460	.072	.036	2.227
9	304.800	9.633	.480	.106	.020	1.903
10	405.380	2.400	.500	.140	.004	1.580
11	457.200	3.200	.505	.130	.006	1.585
12	502.920	4.000	.510	.120	.009	1.590
13	556.870	1.000	.230	.015	.038	1.474
NAT 13						
1	15.240	6.050	.500	.140	.018	1.650
2	54.860	8.025	.527	.089	.017	1.725
3	67.060	10.000	.554	.038	.015	1.800
4	91.440	5.600	.502	.089	.010	1.530

Table A-1. NAT model hydraulic properties.

Soil Layer	Layer Bottom (cm)	K _s (cm/hr)	Porosity	Residual	Alpha (1/cm)	n
5	114.300	1.200	.450	.140	.004	1.260
6	137.160	1.200	.450	.140	.004	1.260
7	167.640	1.200	.450	.140	.004	1.260
8	182.880	9.637	.447	.110	.016	1.840
9	201.170	18.073	.443	.080	.028	2.420
10	231.650	26.510	.440	.050	.040	3.000
11	249.940	19.690	.443	.080	.031	2.550
12	274.320	12.870	.447	.110	.022	2.100
13	295.660	6.050	.450	.140	.012	1.650
14	341.380	4.277	.450	.140	.011	1.627
15	396.240	2.503	.450	.140	.009	1.603
16	435.560	.730	.450	.140	.007	1.580
17	635.560	1.000	.230	.015	.038	1.474
NAT 14						
1	38.100	3.000	.500	.140	.012	1.650
2	53.340	12.500	.510	.120	.031	1.590
3	68.580	6.700	.510	.120	.019	1.590
4	114.300	.900	.510	.120	.007	1.590
5	129.540	2.950	.505	.130	.010	1.620
6	568.150	5.000	.500	.140	.012	1.650
7	768.150	1.000	.230	.015	.038	1.474
NAT 15						
1	30.480	.850	.510	.120	.009	1.590
2	45.720	2.925	.505	.130	.012	1.620
3	60.960	5.000	.500	.140	.015	1.650
4	76.200	3.000	.505	.130	.012	1.620
5	106.700	1.000	.510	.120	.009	1.590
6	121.920	6.750	.510	.120	.016	1.590
7	428.850	12.500	.510	.120	.023	1.590
8	628.850	1.000	.230	.015	.038	1.474
NAT 16						
1	30.480	5.000	.510	.120	.026	1.590
2	60.960	2.950	.505	.090	.019	1.595
3	114.300	.900	.500	.060	.013	1.600

Table A-1. NAT model hydraulic properties.

Soil Layer	Layer Bottom (cm)	K _s (cm/hr)	Porosity	Residual	Alpha (1/cm)	n
4	129.540	.900	.500	.060	.010	1.600
5	175.260	6.700	.505	.090	.018	1.595
6	213.360	12.500	.510	.120	.026	1.590
7	243.840	12.500	.510	.120	.026	1.590
8	274.320	12.500	.510	.120	.026	1.590
9	350.520	8.750	.505	.130	.019	1.620
10	365.760	5.000	.500	.140	.012	1.650
11	396.240	3.000	.505	.130	.011	1.620
12	426.720	1.000	.510	.120	.009	1.590
13	438.910	6.750	.510	.120	.018	1.590
14	460.250	12.500	.510	.120	.026	1.590
15	472.440	6.750	.510	.120	.019	1.590
16	487.680	1.000	.510	.120	.012	1.590
17	557.780	1.000	.230	.015	.038	1.474
NAT 15 USGS						
1	600.000	4.000	.510	.120	.026	1.590
2	800.000	.500	.230	.015	.038	1.474

Appendix B

Simulation Daily and Annual Flux Values

Appendix B

Simulation Daily and Annual Flux Values

This appendix contains the annual and daily flux values predicted by the calibrated models for each NAT location. The annual flux values of draining water entering the basalt interfaces are presented in Table B-1 and the daily flux values are illustrated in graphical form in Figures B-1 through B-16. The 1995 flux values are for the period January 1 through April 30.

Table B-1. Annual water flux entering the basalt interface.

Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)
NAT-1							
1952	0.24	1963	3.36	1974	1.42	1985	0.85
1953	0.21	1964	1.93	1975	1.49	1986	1.91
1954	0.22	1965	3.40	1976	1.26	1987	2.57
1955	0.25	1966	2.72	1977	1.02	1988	1.67
1956	0.28	1967	1.63	1978	0.81	1989	1.14
1957	1.46	1968	1.11	1979	0.68	1990	0.86
1958	2.73	1969	1.12	1980	0.62	1991	0.89
1959	1.54	1970	1.81	1981	0.73	1992	0.82
1960	1.16	1971	1.30	1982	0.84	1993	0.72
1961	1.37	1972	1.34	1983	0.78	1994	0.63
1962	4.30	1973	1.84	1984	0.72	1995	0.19
NAT-2							
1952	9.40	1963	3.81	1974	3.87	1985	8.35
1953	9.03	1964	2.07	1975	6.23	1986	30.2
1954	3.12	1965	1.50	1976	3.46	1987	17.6
1955	1.82	1966	6.42	1977	1.94	1988	3.55
1956	48.1	1967	3.19	1978	15.0	1989	1.96
1957	24.3	1968	1.86	1979	10.1	1990	13.3
1958	6.68	1969	25.1	1980	27.2	1991	3.51
1959	3.15	1970	4.71	1981	3.68	1992	1.95
1960	39.7	1971	2.63	1982	2.38	1993	18.3
1961	2.79	1972	27.8	1983	5.76	1994	3.59
1962	59.4	1973	18.9	1984	3.08	1995	0.75
NAT-3							
1952	1.38	1963	2.74	1974	1.05	1985	0.41

Table B-1. Annual water flux entering the basalt interface.

Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)
1953	0.95	1964	1.64	1975	1.19	1986	0.57
1954	0.71	1965	4.78	1976	1.03	1987	1.48
1955	0.56	1966	2.65	1977	0.81	1988	1.09
1956	0.48	1967	1.55	1978	0.63	1989	0.79
1957	1.38	1968	1.05	1979	0.55	1990	0.69
1958	2.11	1969	1.02	1980	0.49	1991	0.64
1959	1.32	1970	1.45	1981	0.49	1992	0.55
1960	1.04	1971	1.12	1982	0.48	1993	0.47
1961	1.10	1972	1.22	1983	0.44	1994	0.41
1962	2.58	1973	1.27	1984	0.41	1995	0.12
NAT-4							
1952	0.80	1963	0.70	1974	0.74	1985	0.41
1953	0.64	1964	0.63	1975	0.81	1986	0.38
1954	0.50	1965	3.07	1976	0.73	1987	0.36
1955	0.42	1966	1.74	1977	0.57	1988	0.33
1956	0.42	1967	1.05	1978	0.47	1989	0.30
1957	0.57	1968	0.77	1979	0.47	1990	0.32
1958	0.63	1969	1.09	1980	0.42	1991	0.32
1959	0.53	1970	1.10	1981	0.41	1992	0.28
1960	0.43	1971	0.88	1982	0.39	1993	0.27
1961	0.35	1972	0.83	1983	0.37	1994	0.27
1962	0.52	1973	0.66	1984	0.39	1995	0.08
NAT-5							
1952	0.48	1963	7.99	1974	5.50	1985	2.74
1953	1.02	1964	4.54	1975	4.38	1986	10.9
1954	1.87	1965	5.79	1976	3.96	1987	9.88
1955	1.76	1966	6.90	1977	2.96	1988	6.56
1956	14.5	1967	5.73	1978	2.25	1989	3.58
1957	15.6	1968	3.49	1979	2.49	1990	4.04
1958	8.08	1969	3.76	1980	7.11	1991	5.16
1959	4.53	1970	5.39	1981	6.54	1992	3.26
1960	13.4	1971	3.73	1982	4.03	1993	2.41

Table B-1. Annual water flux entering the basalt interface.

Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)
1961	4.15	1972	9.59	1983	2.99	1994	2.41
1962	23.8	1973	7.34	1984	2.85	1995	0.76
NAT-6							
1952	81.8	1963	4.65	1974	3.10	1985	84.2
1953	81.7	1964	3.04	1975	77.6	1986	213.
1954	1.27	1965	5.11	1976	3.38	1987	46.4
1955	1.00	1966	83.9	1977	1.45	1988	2.83
1956	59.1	1967	1.82	1978	22.9	1989	68.9
1957	126.	1968	0.97	1979	14.7	1990	70.4
1958	11.8	1969	32.6	1980	39.8	1991	2.26
1959	1.62	1970	9.03	1981	6.05	1992	2.51
1960	142.	1971	2.49	1982	5.82	1993	16.0
1961	11.9	1972	164.	1983	13.4	1994	2.62
1962	160.	1973	24.2	1984	74.4	1995	20.3
NAT-7							
1952	0.29	1963	8.06	1974	4.74	1985	3.78
1953	0.76	1964	5.93	1975	4.50	1986	8.74
1954	1.21	1965	9.85	1976	3.96	1987	7.73
1955	1.29	1966	7.26	1977	3.10	1988	5.30
1956	6.12	1967	5.01	1978	2.43	1989	3.27
1957	12.5	1968	3.66	1979	2.37	1990	4.33
1958	7.42	1969	6.06	1980	4.08	1991	4.35
1959	4.11	1970	5.29	1981	4.99	1992	3.05
1960	8.84	1971	4.15	1982	3.81	1993	2.49
1961	4.63	1972	8.46	1983	3.07	1994	2.06
1962	16.7	1973	6.05	1984	3.18	1995	0.83
NAT-8							
1952	0.15	1963	5.72	1974	2.51	1985	0.83
1953	0.29	1964	2.85	1975	1.80	1986	3.96
1954	0.44	1965	2.19	1976	1.38	1987	7.17
1955	0.42	1966	3.36	1977	1.12	1988	4.55
1956	10.7	1967	3.22	1978	0.92	1989	2.49

Table B-1. Annual water flux entering the basalt interface.

Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)
1957	16.5	1968	2.12	1979	0.78	1990	3.09
1958	5.57	1969	1.55	1980	1.54	1991	3.09
1959	2.79	1970	1.29	1981	1.96	1992	2.04
1960	14.0	1971	1.08	1982	1.51	1993	1.49
1961	2.78	1972	5.72	1983	1.20	1994	1.17
1962	25.3	1973	4.32	1984	0.98	1995	0.33
NAT-9							
1952	0.14	1963	10.8	1974	6.15	1985	5.80
1953	0.13	1964	9.10	1975	6.51	1986	6.40
1954	0.13	1965	10.8	1976	6.27	1987	8.66
1955	0.15	1966	10.5	1977	5.45	1988	6.74
1956	0.23	1967	6.95	1978	4.44	1989	5.05
1957	0.54	1968	5.31	1979	3.92	1990	4.31
1958	3.92	1969	6.37	1980	3.73	1991	4.65
1959	5.58	1970	8.34	1981	4.44	1992	4.25
1960	4.81	1971	6.31	1982	5.14	1993	3.91
1961	6.24	1972	6.54	1983	4.86	1994	3.52
1962	7.30	1973	7.47	1984	4.68	1995	1.11
NAT-10							
1952	0.10	1963	2.09	1974	0.96	1985	0.23
1953	0.14	1964	1.17	1975	0.84	1986	0.23
1954	0.19	1965	1.10	1976	0.65	1987	0.63
1955	0.22	1966	1.51	1977	0.49	1988	0.87
1956	0.20	1967	1.25	1978	0.37	1989	0.63
1957	1.03	1968	0.81	1979	0.29	1990	0.47
1958	2.10	1969	0.59	1980	0.25	1991	0.48
1959	1.13	1970	0.74	1981	0.26	1992	0.44
1960	0.70	1971	0.67	1982	0.31	1993	0.36
1961	0.72	1972	0.81	1983	0.30	1994	0.29
1962	1.09	1973	1.45	1984	0.26	1995	0.08
NAT-11							
1952	2.67	1963	3.02	1974	2.03	1985	0.83

Table B-1. Annual water flux entering the basalt interface.

Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)
1953	21.8	1964	1.92	1975	1.48	1986	45.3
1954	1.79	1965	3.89	1976	1.02	1987	15.4
1955	0.84	1966	27.1	1977	0.62	1988	2.20
1956	19.9	1967	2.35	1978	0.55	1989	1.15
1957	48.9	1968	1.27	1979	0.50	1990	19.6
1958	2.89	1969	2.13	1980	8.28	1991	2.02
1959	1.23	1970	1.39	1981	2.42	1992	1.08
1960	54.3	1971	1.14	1982	1.27	1993	0.73
1961	1.52	1972	53.8	1983	0.94	1994	0.54
1962	62.4	1973	2.75	1984	0.94	1995	4.50
NAT-12							
1952	5.49	1963	150.	1974	3.88	1985	1.52
1953	79.7	1964	4.06	1975	2.48	1986	148.
1954	3.52	1965	2.18	1976	2.00	1987	32.7
1955	2.03	1966	1.52	1977	1.45	1988	3.81
1956	49.7	1967	72.3	1978	3.82	1989	2.11
1957	136.	1968	3.88	1979	3.47	1990	48.0
1958	4.17	1969	2.13	1980	31.4	1991	3.80
1959	2.45	1970	10.7	1981	3.76	1992	2.11
1960	141.	1971	3.93	1982	2.11	1993	2.23
1961	2.19	1972	2.20	1983	1.72	1994	1.89
1962	150.	1973	177.	1984	1.49	1995	12.3
NAT-13							
1952	30.5	1963	5.41	1974	2.65	1985	30.1
1953	26.8	1964	4.50	1975	24.3	1986	58.8
1954	2.18	1965	4.75	1976	2.66	1987	36.1
1955	1.31	1966	31.6	1977	1.47	1988	3.37
1956	55.2	1967	2.44	1978	42.0	1989	1.66
1957	50.4	1968	1.36	1979	27.4	1990	42.4
1958	20.1	1969	57.7	1980	37.5	1991	2.45
1959	2.38	1970	15.6	1981	10.7	1992	3.67
1960	83.8	1971	2.34	1982	12.5	1993	31.9

Table B-1. Annual water flux entering the basalt interface.

Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)
1961	14.1	1972	64.2	1983	25.0	1994	3.55
1962	114.	1973	41.7	1984	2.43	1995	1.50
NAT-14							
1952	0.30	1963	3.42	1974	3.80	1985	2.55
1953	0.47	1964	3.21	1975	3.51	1986	3.82
1954	0.40	1965	6.41	1976	2.75	1987	2.98
1955	0.37	1966	4.02	1977	1.83	1988	2.05
1956	0.63	1967	2.62	1978	2.23	1989	1.76
1957	1.49	1968	2.12	1979	2.47	1990	1.79
1958	1.97	1969	4.59	1980	2.44	1991	1.36
1959	1.52	1970	3.73	1981	2.28	1992	1.25
1960	1.75	1971	3.12	1982	2.05	1993	1.56
1961	1.92	1972	3.15	1983	2.28	1994	1.49
1962	3.45	1973	3.40	1984	2.39	1995	0.36
NAT-15							
1952	0.17	1963	1.01	1974	1.11	1985	0.63
1953	0.20	1964	0.91	1975	0.97	1986	1.08
1954	0.10	1965	2.41	1976	0.66	1987	0.71
1955	0.06	1966	1.24	1977	0.33	1988	0.40
1956	0.18	1967	0.64	1978	0.50	1989	0.29
1957	0.63	1968	0.46	1979	0.56	1990	0.32
1958	0.74	1969	1.73	1980	0.54	1991	0.19
1959	0.42	1970	1.14	1981	0.49	1992	0.17
1960	0.45	1971	0.85	1982	0.40	1993	0.27
1961	0.48	1972	0.89	1983	0.47	1994	0.27
1962	1.15	1973	0.97	1984	0.56	1995	0.05
NAT-16							
1952	10.3	1963	11.6	1974	6.84	1985	6.74
1953	37.1	1964	9.17	1975	6.71	1986	72.9
1954	8.34	1965	12.6	1976	6.22	1987	50.3
1955	5.01	1966	48.9	1977	5.17	1988	10.2
1956	65.0	1967	9.52	1978	4.03	1989	5.23

Table B-1. Annual water flux entering the basalt interface.

Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)	Year	Total Drainage (cm)
1957	71.3	1968	6.00	1979	3.83	1990	62.3
1958	11.2	1969	9.09	1980	41.8	1991	9.58
1959	6.23	1970	8.06	1981	10.3	1992	5.36
1960	109.	1971	5.93	1982	6.62	1993	4.27
1961	6.93	1972	85.2	1983	5.10	1994	3.63
1962	146.	1973	9.81	1984	5.20	1995	1.10
USGS NAT-15							
1952	0.00	1963	10.2	1974	8.40	1985	7.47
1953	0.00	1964	8.84	1975	7.74	1986	9.15
1954	0.00	1965	12.2	1976	7.40	1987	9.07
1955	0.00	1966	9.56	1977	5.56	1988	6.05
1956	0.05	1967	5.97	1978	4.37	1989	4.53
1957	0.43	1968	4.56	1979	5.44	1990	4.07
1958	4.35	1969	8.31	1980	6.02	1991	4.40
1959	6.14	1970	10.4	1981	6.12	1992	3.96
1960	4.82	1971	6.29	1982	6.22	1993	3.82
1961	6.09	1972	6.53	1983	5.59	1994	5.20
1962	7.89	1973	7.12	1984	6.46	1995	1.66

Figure B-1. NAT-1 daily flux values.

Figure B-2. NAT-2 daily flux values.

Figure B-3. NAT-3 daily flux values.

Figure B-4. NAT-4 daily flux values.

Figure B-5. NAT-5 daily flux values.

Figure B-6. NAT-6 daily flux values.

Figure B-7. NAT-7 daily flux values.

Figure B-8. NAT-8 daily flux values.

Figure B-9. NAT-9 daily flux values.

Figure B-10. NAT-10 daily flux values.

Figure B-11. NAT-11 daily flux values.

Figure B-12. NAT-12 daily flux values.

Figure B-13. NAT-13 daily flux values.

Figure B-14. NAT-14 daily flux values.

Figure B-15. NAT-15 daily flux values.

Figure B-16. NAT-16 daily flux values.

Figure B-17. USGS NAT-15 daily flux values.

Appendix C

Simulation Daily Evaporative Depths

Appendix C

Simulation Daily Evaporative Depths

This appendix contains the daily evaporative depth for 1963, 1990, and 1976 predicted by the calibrated models for each NAT location. The daily evaporative depths are illustrated graphically in Figures C-1 through C-16.

Figure C-1. NAT-1 daily evaporative depths.

Figure C-2. NAT-2 daily evaporative depths.

Figure C-3. NAT-3 daily evaporative depths.

Figure C-4. NAT-4 daily evaporative depths.

Figure C-5. NAT-5 daily evaporative depths.

Figure C-6. NAT-6 daily evaporative depths.

Figure C-7. NAT-7 daily evaporative depths.

Figure C-8. NAT-8 daily evaporative depths.

Figure C-9. NAT-9 daily evaporative depths.

Figure C-10. NAT-10 daily evaporative depths.

Figure C-11. NAT-11 daily evaporative depths.

Figure C-12. NAT-12 daily evaporative depths.

Figure C-13. NAT-13 daily evaporative depths.

Figure C-14. NAT-14 daily evaporative depths.

Figure C-15. NAT-15 daily evaporative depths.

Figure C-16. NAT-16 daily evaporative depths.

Figure C-17. USGS NAT-15 daily evaporative depths.

Appendix D

Abbreviated Infiltration Distribution Rates

Appendix D

Abbreviated Infiltration Distribution Rates

This appendix contains the abbreviated infiltration distribution rate data used to define the low, medium, and high infiltration amounts. The data are presented in tables D-1 through D-3 and are for the low, medium, and high infiltration rates at the 75-cm depth at NATs 4, 8, and 13, respectively..

Table D-1. Low infiltration rate data.

Time (yr)	Infiltration rate (cm/day)
1952.0000	0.0013390
1964.9973	0.0013390
1964.9973	0.1401500
1965.0575	0.1401500
1965.0575	0.0013390
1995.3287	0.0013390

Table D-2. Medium infiltration rate data.

Time (yr)	Infiltration rate (cm/day)	Time (yr)	Infiltration rate (cm/day)
1952.0000	0.0011901	1960.2329	3.4640000
1956.2164	0.0011901	1960.2356	3.4640000
1956.2164	9.7830000	1960.2356	5.2176666
1956.2192	9.7830000	1960.2439	5.2176666
1956.2192	11.9200001	1960.2439	1.5895000
1956.2219	11.9200001	1960.2493	1.5895000
1956.2219	3.0139999	1960.2493	0.0011901
1956.2246	3.0139999	1962.2329	0.0011901
1956.2246	1.3609999	1962.2329	2.2110000
1956.2274	1.3609999	1962.2356	2.2110000
1956.2274	0.0011901	1962.2356	5.2884002
1957.1561	0.0011901	1962.2493	5.2884002
1957.1561	1.5140001	1962.2493	1.5615001
1957.1781	1.5140001	1962.2548	1.5615001
1957.1781	0.0011901	1962.2548	0.0011901
1960.2329	0.0011901	1966.1891	0.0011901

Table D-2. Medium infiltration rate data.

Time (yr)	Infiltration rate (cm/day)	Time (yr)	Infiltration rate (cm/day)
1966.1891	1.5555000	1990.1699	3.9310000
1966.1946	1.5555000	1990.1726	3.9310000
1966.1946	0.0011901	1990.1726	1.8460000
1972.1726	0.0011901	1990.1753	1.8460000
1972.1726	1.5000000	1990.1753	0.0011901
1972.1781	1.5000000	1995.3287	0.0011901
1972.1781	2.4430001		
1972.1918	2.4430001		
1972.1918	1.0010000		
1972.1946	1.0010000		
1972.1946	0.0011901		
1980.1398	0.0011901		
1980.1398	5.6310000		
1980.1425	5.6310000		
1980.1425	2.3290000		
1980.1453	2.3290000		
1980.1453	1.1780000		
1980.1479	1.1780000		
1980.1479	0.0011901		
1986.1398	0.0011901		
1986.1398	1.3033333		
1986.1479	1.3033333		
1986.1479	2.3562498		
1986.1589	2.3562498		
1986.1589	1.0820000		
1986.1616	1.0820000		
1986.1616	0.0011901		
1987.1699	0.0011901		
1987.1699	2.4460001		
1987.1753	2.4460001		
1987.1753	1.0160000		
1987.1781	1.0160000		
1987.1781	0.0011901		
1990.1699	0.0011901		

Table D-3. High infiltration rate data.

Time (yr)	Infiltration rate (cm/day)	Time (yr)	Infiltration rate (cm/day)
1952.0000	0.0073766	1957.1781	0.0073766
1952.2684	0.0073766	1958.1343	0.0073766
1952.2684	3.9473999	1958.1343	3.1600001
1952.2822	3.9473999	1958.1479	3.1600001
1952.2822	5.6009998	1958.1479	0.0073766
1952.2849	5.6009998	1960.2274	0.0073766
1952.2849	3.3050001	1960.2274	8.8310003
1952.2877	3.3050001	1960.2301	8.8310003
1952.2877	0.0073766	1960.2301	15.0660000
1953.0273	0.0073766	1960.2439	15.0660000
1953.0273	5.7659998	1960.2439	4.5900002
1953.0328	5.7659998	1960.2466	4.5900002
1953.0328	8.6099997	1960.2466	2.3280001
1953.0356	8.6099997	1960.2493	2.3280001
1953.0356	2.8274999	1960.2493	0.0073766
1953.0411	2.8274999	1961.1068	0.0073766
1953.0411	0.0073766	1961.1068	3.0227499
1956.2137	0.0073766	1961.1178	3.0227499
1956.2137	5.0120001	1961.1178	0.0073766
1956.2164	5.0120001	1962.2301	0.0073766
1956.2164	23.2200012	1962.2301	4.7849998
1956.2219	23.2200012	1962.2329	4.7849998
1956.2219	8.1000004	1962.2329	17.6983337
1956.2246	8.1000004	1962.2493	17.6983337
1956.2246	2.7709999	1962.2493	5.1560001
1956.2274	2.7709999	1962.2521	5.1560001
1956.2274	0.0073766	1962.2521	2.4200001
1957.1479	0.0073766	1962.2548	2.4200001
1957.1479	3.5323334	1962.2548	0.0073766
1957.1561	3.5323334	1966.1836	0.0073766
1957.1561	5.0352859	1966.1836	5.9070001
1957.1753	5.0352859	1966.1863	5.9070001
1957.1753	2.6180000	1966.1863	9.8549995
1957.1781	2.6180000	1966.1918	9.8549995

Table D-3. High infiltration rate data.

Time (yr)	Infiltration rate (cm/day)	Time (yr)	Infiltration rate (cm/day)
1966.1918	3.6750000	1975.2904	2.1440001
1966.1946	3.6750000	1975.2932	2.1440001
1966.1946	0.0073766	1975.2932	0.0073766
1969.2384	0.0073766	1978.2192	0.0073766
1969.2384	4.7170000	1978.2192	4.3150001
1969.2411	4.7170000	1978.2246	4.3150001
1969.2411	7.3189998	1978.2246	6.8369999
1969.2439	7.3189998	1978.2301	6.8369999
1969.2439	9.6830006	1978.2301	8.3990002
1969.2548	9.6830006	1978.2356	8.3990002
1969.2548	3.0929999	1978.2356	2.9010000
1969.2603	3.0929999	1978.2411	2.9010000
1969.2603	0.0073766	1978.2411	0.0073766
1970.1151	0.0073766	1979.2219	0.0073766
1970.1151	2.0780001	1979.2219	2.7318890
1970.1178	2.0780001	1979.2466	2.7318890
1970.1178	6.7729998	1979.2466	0.0073766
1970.1206	6.7729998	1980.1370	0.0073766
1970.1206	3.3420000	1980.1370	4.8189998
1970.1233	3.3420000	1980.1398	4.8189998
1970.1233	0.0073766	1980.1398	21.9599991
1972.1616	0.0073766	1980.1425	21.9599991
1972.1616	4.5303330	1980.1425	7.6430001
1972.1699	4.5303330	1980.1453	7.6430001
1972.1699	6.9591422	1980.1453	2.8130000
1972.1891	6.9591422	1980.1479	2.8130000
1972.1891	3.3510001	1980.1479	0.0073766
1972.1918	3.3510001	1983.1644	0.0073766
1972.1918	0.0073766	1983.1644	2.6828747
1973.2603	0.0073766	1983.1863	2.6828747
1973.2603	3.7248333	1983.1863	0.0073766
1973.2767	3.7248333	1985.2548	0.0073766
1973.2767	4.5675001	1985.2548	3.3609996
1973.2877	4.5675001	1985.2686	3.3609996
1973.2877	0.0073766	1985.2686	5.0143332
1975.2904	0.0073766	1985.2767	5.0143332

Table D-3. High infiltration rate data.

Time (yr)	Infiltration rate (cm/day)	Time (yr)	Infiltration rate (cm/day)
1985.2767	2.0610001	1992.1151	0.0073766
1985.2794	2.0610001	1992.1151	2.1170001
1985.2794	0.0073766	1992.1178	2.1170001
1986.1288	0.0073766	1992.1178	0.0073766
1986.1288	4.1659999	1993.2329	0.0073766
1986.1370	4.1659999	1993.2329	3.2135458
1986.1370	5.8832855	1993.2631	3.2135458
1986.1561	5.8832855	1993.2631	0.0073766
1986.1561	3.3610001	1995.3287	0.0073766
1986.1589	3.3610001		
1986.1589	0.0073766		
1987.1671	0.0073766		
1987.1671	4.8600001		
1987.1699	4.8600001		
1987.1699	21.8700008		
1987.1726	21.8700008		
1987.1726	7.6430001		
1987.1753	7.6430001		
1987.1753	2.7240000		
1987.1781	2.7240000		
1987.1781	0.0073766		
1990.1644	0.0073766		
1990.1644	4.1830001		
1990.1671	4.1830001		
1990.1671	15.7600002		
1990.1699	15.7600002		
1990.1699	19.8299999		
1990.1726	19.8299999		
1990.1726	5.5510001		
1990.1753	5.5510001		
1990.1753	2.4830000		
1990.1781	2.4830000		
1990.1781	0.0073766		