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Civilian Radioactive Waste Management System
U.S. Geological Survey

INFIL V2.0

VALIDATION TEST REPORT

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Prepared for:

U.S. Department of Energy
Yucca Mountain Site Characterization Office
P.O. Box 30307
North Las Vegas, Nevada 89036-0307

Prepared by:

U.S. Geological Survey

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Prepared by:

For Joseph Hevesi
U.S. Geological Survey

Date 9/26/01

Verified by:

Dwight Hoxie
Technical Reviewer
U.S. Geological Survey

Date 09/26/01

Approved by:

William Scott
U.S. Geological Survey

Date 9/26/01

Reviewed by:

~~Dianne Spence~~ Edward Miller 09/28/01
ITSMA

Date 09/28/01

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Revision Number	Effective Date	**Description of and Reason for Revision**
0	8/29/2000	Initial Release

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1. PURPOSE

The Validation Test Report (VTR) that follows is part of the software baseline documentation that the U.S. Geological Survey-Yucca Mountain Project Branch (USGS-YMPB) must submit to qualify the use of INFIL V2.0 to support the Analysis Model Report (AMR) *Similuation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001). The VTR has been developed to meet the requirements described in Requirements Document 10307-RD-2.0-00 (RD) and Design Document 10307-DD-2.0-00 (DD). The primary function of the INFIL V2.0 program is to perform a root-zone water balance from which net infiltration can be derived. It is noted that this approach does not necessarily represent the physics of infiltration in soils, but uses a water volume calculation approach in the mathematical and numerical models. This model has been compared successfully to several independent approaches to estimating net infiltration and recharge, and more rigorous methods based, for example, on detailed numerical solution of the differential equations of ground-water and surface-water flow are not feasible for use in this large-scale application. The sum of results for net infiltration simulations are to be presented in USGS (2001). These calculations are dependent on post-processing routines discussed in the cited AMR.

INFIL V2.0 supports the net infiltration model and analysis to be documented in USGS (2001), that are concerned specifically with estimating the spatial distribution of net infiltration in the vicinity of the potential Yucca Mountain repository under present-day and projected future climatic conditions. In accordance with the screening criteria listed in Software Categorization, Section 5.1 of AP-SI.1Q, *Software Management,* the net infiltration model and analysis are of Level 2 importance in addressing the factors of the post-closure safety case for the potential repository in the unsaturated zone at Yucca Mountain. The net infiltration model is founded on the application of INFIL V2.0 based on standard distributed-parameter water-balance methods to estimate net infiltration as discussed, for example, in Hatton (1998). On this basis, the software program, INFIL V2.0 is deemed to be appropriate for providing estimates of net infiltration that serve as input to and the upper boundary condition for the site-scale UZ flow and transport model.

2. VALIDATION OF INFIL V2.0

2.1 METHOD

This validation test report describes the result for re-execution of the Installation Test Plan 10307-ITP-2.0-00 (ITP), and execution of the Validation Test Plan 10307-VTP-2.0-00 (VTP) submitted for INFIL V2.0. The ITP and the appropriate tests from the controlled VTP were executed to validate the software program INFIL V2.0 performs according to specifications in the RD and DD regarding functionality.

In general, the intended level of precision for most estimates of net infiltration, which is the principal output from INFIL V2.0, is 0.01 mm. The precision and functionality of the calculations performed by the program are validated by ensuring that the water volume balance equation is satisfied (the solution to the water balance equation must be 0, within the level of machine and variable precision). The set of validation tests designed for this VTP are only capable of validating that the software is functioning as intended and within the level of precision intended. The accuracy of model results cannot be validated by the validation tests described in this document. The accuracy of results generated by INFIL V2.0 depends on the accuracy of model inputs, the appropriateness of the assumptions applied in model development, and the adequacy of the model in representing the true physical processes being modeled. More detailed information for intended levels of precision is provided for each test case description.

The collection of test cases assembled for this VTP is designed to ensure that the 16 functionality requirements listed in Section 1.1.2 of the RD and in Section 2.2 of this VTR have been satisfied. Each test case includes a listing of one or more criteria that are used to validate one or more functionality requirements. Each functionality requirement is validated multiple times within the set of test cases. The purpose of multiple validation is to ensure that the functionality requirements are validated across a broad range of conditions that are likely to arise during model application. It is not possible to validate all functionality requirements for all possible combinations of model inputs and run-time conditions; however, the set of test cases used for this VTR is assumed to be provide a sufficient validation for the functionality requirements.

The validation test cases are organized into 6 test sequences. Each test sequence contains multiple test cases that are generally ordered by the complexity of model functionality. The simplest level of model functionality is where all inputs are either turned off or set to zero, and all model components have been de-activated. Simplifying model functionality allows for the validation of the most basic water volume balance calculation (there is no water in the system, thus all outputs must be zero). The complexity of model functionality is progressively increased as model components are activated and additional model inputs are incorporated. This allows for a systematic validation of the various model components and functions. For example, model functionality is simplified if evapotranspiration is enabled but daily precipitation is set to zero, potential evapotranspiration is set to a constant rate of 1 mm/day, and net infiltration and surface water flow routing are disabled. In this example the simplified conditions are designed to test only the loss of water from the root zone as a function of modeled evapotranspiration and the initial water content of the root zone. The level of complexity is increased if daily precipitation and air temperature input are allowed, spatial variability in geospatial input parameters is allowed, and all model functions such as net infiltration, coupled surface water routing, and snow accumulation – snow melt, are all enabled. In this example, the level of model complexity has been increased to test the interaction of the various model components

The organization of multiple validation test cases allows for comparison of results from progressively more complex test cases with results from a sequence of previous tests developed from the simplest "base-case" test condition. Thus, in most cases, the results from later test cases are intended to build on the results of previous test cases in a logical progression from simplified conditions that are restrictive relative to conditions expected during model application, to the actual conditions intended for use during model application.

Validation for each test case is conducted by a visual inspection of the output files generated by INFILv2 using an ASCII text editor, word processing application, or spreadsheet application, and also by hand calculations that can be performed using a spreadsheet application (such as EXCEL). The absence of remarks or checks in the "Fail" column of the matrix for the Validation Test Results (Appendix 2, Table A2-2), is confirmation that all tests passed the acceptance criteria.

2.2 FUNCTIONAL REQUIREMENTS

Net infiltration is the component of infiltrated precipitation, snowmelt, or surface water run-on that has percolated below the zone of evapotranspiration as defined by the depth of the effective root zone, the average depth below the ground surface (at a given location) from which water is removed by evapotranspiration. The estimates of net infiltration are used for defining the upper boundary condition for the site-scale 3-dimensional Unsaturated-Zone Flow and Transport (UZ flow and transport) Model (CRWMS M&O 2000a). Output from this model provides the upper boundary condition for the UZ flow and transport model that is used to generate flow fields for evaluating potential radionuclide transport through the unsaturated zone.

The output from INFIL V2.0 is post-processed to create raster-based, 2-dimensional grids of spatially distributed, time-averaged rates for three different climate stages estimated as likely conditions for the next 10,000 years beyond the present. Each climate stage is represented using a lower bound, a mean, and an upper bound climate, and the corresponding net-infiltration scenario for representing uncertainty in the characterization of daily climate conditions for each climate stage, as well as potential climate variability within each climate stage. The set of nine raster grid maps provide spatially detailed representations of the magnitude and distribution of net-infiltration rates that are used to define specified flux upper boundary conditions for the UZ flow and transport model.

The RD describes the hierarchical structure of INFIL V2.0, and provides the functional requirements that the program calculate infiltration into the root zone, evapotranspiration, net infiltration, and runoff based on identification of watershed domains, climate, soil layer depths, and hydrologic properties of the underlying bedrock. The processes, and therefore the functional requirements of INFIL V2.0 must be satisfied to ensure that the software functions as designed and fulfills the purpose of the application. The specific functionality requirements stated in the VTP that conform to those in the RD are that INFIL V2.0 properly functions to perform the following:

1. Accept input from pre-processing software routines that are documented in USGS (2001) (the pre-processing routines are used to develop the daily climate input and the geospatial parameter input files), as well as from a model control file documented in the User's Manual 10307-UM-2.0-00 (UM) for INFIL V2.0 (see Appendix 1-A). The input formats for daily climate parameters must include an option to allow daily air temperature to either be provided as input in the daily climate input file or be modeled internally by the program as a function of the day-of-year. The input formats for daily climate input must include a format compatible with the output generated by the FORTRAN routine DAILY09, as documented in USGS (2001). The input format for the geospatial parameter file must be compatible with the format of the output generated by the FORTRAN routine WATSHD20, as described in USGS (2001).

2. Apply a multi-layered root zone model for calculating daily net infiltration, evapotranspiration, and runoff. Partition the root zone into 4 layers and define the thickness of each root-zone layer, including the depth to which the root zone extends into bedrock, as a function of the soil depth input parameter and user specified model parameters.

3. Model potential evapotranspiration as an hourly energy balance based on incoming solar radiation, the average daily air temperature, estimated ground heat flux, and topographic parameters included in the geospatial parameter input file. If average daily air temperature is not provided as input, model

daily air temperature as a function of the day-of-year and user specified parameters in the model control file. Model incoming solar radiation on an hourly basis using topographic parameters and the day of year provided as input from the daily climate model.

4. Model the spatial distribution of daily precipitation, air temperature, and potential evapotranspiration as a function of spatially distributed parameters provided by the geospatial parameter input file.

5. Estimate daily snowfall and snowmelt as a function of average daily air temperature. Estimate sublimation as a function of daily potential evapotranspiration.

6. Initiate the daily water balance calculation using an estimate of root zone water content for soil layers at all model nodes.

7. Solve the daily water volume balance equation (equation 1 in the RD and equation 3-3 in this VTR) for all model nodes for all days simulated. All components of the daily water balance must sum to zero (water is conserved), within the expected level of output precision (0.01 mm). The components of the calculation include precipitation (either rain or snow), snowmelt, sublimation, evapotranspiration, change in root zone water storage, runoff, run-on, and drainage (net infiltration) below the root zone.

8. Perform the daily water balance calculation for all grid locations, including surface water routing across all model nodes if runoff is generated at any node in the model domain. Repeat the water balance calculation for all successive days of a continuous simulation period based on the modeled root zone water content of the previous day and the daily climate input for the new day.

9. Estimate daily evapotranspiration as a function of the root zone water content, root density, and modeled potential evapotranspiration.

10. Calculate net infiltration as a function of the root zone water content for the bottom root zone layer, the saturated hydraulic conductivity of the soil, and the bulk saturated hydraulic conductivity of the bedrock or soil underlying the root zone, and evapotranspiration from the bottom root zone layer.

11. Distribute runoff laterally across all model nodes as surface water flow. Couple the surface water routing model component to the root zone water balance model component by allowing surface water run-on to infiltrate into the root zone as a function of the root zone hydraulic conductivity and the available root zone storage capacity. Include the infiltrated run-on as the new root zone water content for the next day simulated.

12. Calculate daily surface water outflow from the model domain and from specified model nodes as daily mean discharge, in cubic-feet-per-second.

13. Output the main components of the daily water volume balance, averaged across all model nodes, for each day of the simulation. This is a primary model output that includes daily precipitation (both rain and snowfall), snow-melt, sublimation, evapotranspiration, change in root zone water storage, runoff, infiltrated run-on, surface water outflow, and drainage (net infiltration) below the root zone. The output terms indicate the daily water volume for each component of the water balance as a spatially averaged water depth, in mm, across the total area of the model domain (the water depth

across all model nodes is averaged). Include as part of the output a check of the daily water balance for all days simulated.

14. Output a summary of the main components of the daily water balance as annual totals and calculated average annual rates, averaged across all model nodes. This is a primary output that indicates the daily water volume for each component of the water balance as a spatially averaged water depth, in mm, across the total area of the model domain.

15. Output the main components of the water balance as average annual rates calculated for all model nodes. This is a primary output that indicates a time-averaged rate, in mm/year, for each component of the water balance, for all nodes in the model domain. The time-averaged rates are calculated using the daily water balance results at each node. Include as part of the output a check of the average annual water balance at all model nodes. The output must include the x-y coordinate of each model node so that the results can be easily mapped, and must be in the correct format to be used as input for the post-processing routine MAPADD20, as described in USGS (2001).

16. Output additional information that can be used for model testing and analysis of model results. The additional information is secondary output where the generation of output files is optional and is controlled by user-defined options in the model control file. The optional output files include map files for annual totals or multi-annual averages, map files for the daily water balance results for specified days of the simulation period, and a map file of root zone layer parameters calculated by the program. Although the secondary output is non-essential for the intended model application, some of the optional output is used as part of model validation.

As noted elsewhere, the test cases used for program validation are organized into a set of 6 test sequences (Test Sequence 0 through Test Sequence 5) designed to validate that the software program correctly performs all functional requirements. Test sequence 0 provides an overall test of the model inputs intended for use during model application. This test sequence validates that the program will process the model inputs as intended, model functions are performed as intended, and the water volume balance is satisfied. Test sequence 1 consists of a modified set of conditions to allow a more focused validation of the layered root zone system in response to initial conditions and variations in soil and bedrock properties only. Daily climate input is disabled (precipitation and evapotranspiration are set to 0) to allow for a direct validation of specific root zone functions. Test sequence 2 consists of validating the response of the layered root zone system to various conditions defined by controlling potential evapotranspiration. Daily precipitation is still disabled and thus the test sequence involves model validation based on initial conditions. Test sequence 3 consists of applying controlled conditions in terms of both daily precipitation and daily potential evapotranspiration for a more integrated test of the intended multi-layered root zone functions. Test sequence 4 focuses on validating the coupled surface water routing model component based on applying controlled model conditions in terms of a combination of modified daily climate input, geospatial input parameters, and root zone properties. Test sequence 5 is used to validate the snowfall – snow-melt model component by controlling daily air temperature input.

3. CONCEPTUAL MODEL OF INFILTRATION: SCIENTIFIC APPROACH

3.1 NUMERICAL REPRESENTATION OF THE CONCEPTUAL MODEL

3.1.1 Mathematical Concepts

The numerical model is a digital representation of the mathematical concepts that describe the conceptual model of net infiltration described in Section 6.1. In most cases, an exact mathematical formulation of the physical processes being modeled is not required and in many cases is not possible. An application of approximate mathematical formulations is an essential requirement for computational efficiency and practical applicability of the numerical model. The level of accuracy needed for an approximate representation depends on the sensitivity of the UZ flow and transport models to net infiltration, in conjunction with the level of accuracy needed for results obtained with the models to evaluate potential repository performance (CRWMS M&O, 2000a).

From the documentation for INFIL, version 1, the water balance at user specified site locations is shown to be based on the principle of the conservation of mass of water:

$$P + A + U + \Delta Ws + \Delta Ss + \Delta Bs + Li + Ron - Roff - D - E - T - Lo - Ex = 0 \qquad \text{(Eq. 3-1)}$$

where P is precipitation, A is applied water (man induced), U is upward flow, ΔW_s is change in soil water storage, ΔS_s is change in surface storage, ΔB_s is change in above ground biomass storage, L_i is lateral flow in, R_{on} is surface run-on, R_{off} is surface runoff, D is deep drainage or percolation, E is evaporation, T is transpiration, L_o is lateral flow out, and $-E_x$ is extraction of water (man-induced). Equation 3-3 states that the sum of all inputs, outputs, and changes in storage in the hydrologic system must equal zero. To be applied, the equation must be defined over some arbitrary time interval and over some arbitrary volume or depth in the soil. In most cases, the general form of the water-balance equation can be greatly simplified by assuming one or more of the terms to be zero or negligible in magnitude. The authors have simplified Eq. 3-1 as shown in Eq. 3-2. The term B_s and E_x can often be set to zero, R_{on} and R_{off} are combined into a single term R, and E and T can be combined into a single term for evapotranspiration (ET).

$$P + \Delta W_s - D - ET - R = 0 \qquad \text{(Eq. 3-2)}$$

The current (1999) model development supplements and enhances a preceding 1996 model, particularly with respect to evapotranspiration from the root zone and the infiltration of surface run-on in the channels of washes. In addition, the current (1999) model uses updated model inputs for bedrock geology and soil depth. INFIL V2.0 implements the same approach for calculating the water balance, with Equation 3-2 rewritten to provide more detail with respect to the components of precipitation. The governing equation for the root zone water volume balance at each node is written as:

$$Prs - SF + SM + IR - CRZWC - ET - NI - O = 0 \qquad \text{(Eq. 3-3)}$$

where *Prs* is precipitation (rain or snow), *SF* is snowfall, *SM* is snowmelt, *IR* is infiltrated surface water run-on, *CRZWC* is the change in root zone water content, *ET* is evapotranspiration, *NI* is net infiltration, and *O* is surface water outflow. The parameters included in Equation 3-3 are developed through the software program functional requirements and may be considered to constrain the design of the software.

The process of sublimation of accumulated snowfall is also included in the model and is provided as an output term. To include the sublimation term in the root zone water balance, Equation 3-3 is modified to:

$$Pr + SF - CSP - S + IR - CRZWC - ET - NI - O = 0 \qquad \text{(Eq. 3-4)}$$

where *Pr* is precipitation as rain only and *CSP* is the change in snow pack depth and S is sublimation.

All model nodes have equivalent areas and thus the water volume balance calculation is reduced to a water depth balance for a daily time step, in units of millimeters per day. Water contents for each root zone layer at each node are converted to water depths using layer thickness, which depends on soil depth and is thus variable from node to node. Equations 3-3 and 3-4 state that the sum of all inputs, outputs and changes in storage in the hydrologic system must equal zero.

Equation 3-4 is solved using the daily climate input and modeled potential evapotranspiration. Daily climate input may or may not include daily air temperature, but must at minimum include daily precipitation (although all daily precipitation input values can equal 0), the year number, and the day of year number. If daily air temperature is not provided as input, it is modeled by the program as a daily mean air temperature using an annual sine-wave function:

$$T\alpha = [17.3 - 11.74\, SIN\, [(DN/366) * 2 * \Pi - 1.3)\} - 273.15 \qquad \text{(Eq. 3-5)}$$

where *DN* is the day of the year and $T\alpha$ is the modeled daily mean air temperature in Kelvins (*K*).

Air temperature and the day of year are needed model potential evapotranspiration using the equation developed by Priestley and Taylor (1972)

$$\lambda E = \alpha S/(S+\gamma) \qquad \text{(Eq. 3-6)}$$

where α, an empirical coefficient, S is the slope of the saturation vapor pressure-temperature curve, γ is the psychrometric constant, R_n is net radiation, G is soil-heat flux. The term α, was determined to be 1.26 for freely evaporating surfaces (Priestley and Taylor, 1972; Stewart and Rouse, 1977; and Eichinger and others, 1996). The Priestley-Taylor equation has been modified by several researchers to relate their empirical coefficient, α, to seasonal changes in soil water content (Davies and Allen, 1973; Flint and Childs, 1991), and has been described as successfully used in arid and semi-arid environments (deBruin, 1988; Stannard, 1993). This equation has the added benefit of minimal data requirements. For soil-water-limited conditions the relation between α and soil water content is empirical but works well for many surface conditions (Davies and Allen, 1973; Flint and Childs, 1991).

The evapotranspiration subroutine calculates actual evapotranspiration using a modified Priestley-Taylor equation (Eq. 3-6) where α is replaced with α' which is modeled as:

$$\alpha' = \alpha\ (1 - e^{\beta\Theta}) \qquad \text{(Eq. 3-7)}$$

where α is taken as 1.26, β is a fitting parameter ranging from approximately -1.5 to –10.0 and Θ is relative saturation:

$$\Theta = (\theta - \theta_r)/(\theta_s - \theta_r) \qquad \text{(Eq. 3-8)}$$

where θ is soil-water content, θ_s is porosity, θ_r is residual saturation for plant transpiration (soil-water content at -60 bars water potential, which is the approximate mean minimum xylem potential for the plants in the Yucca Mountain area). The parameter $s/(s+\gamma)$, extracted from Table A.3 in Campbell (1977), is modeled as:

$$S/(S+\gamma) = -13.281 = (0.083684/K)T\alpha - (0.00012375/K^2)\,T\alpha^2 \qquad \text{(Eq. 3-9)}$$

Net radiation (R_n, w/m^2) is modeled as:

$$R_n = -71 + 0.72 * K\downarrow \qquad \text{(Eq. 3-10)}$$

where $K\downarrow$ is modeled incoming solar radiation (w/m^2). Soil-heat flux (G, w/m^2) is modeled as:

$$G- = -20 + 0.386\,R_n \qquad \text{(Eq. 3-11)}$$

Solar radiation, net radiation and soil heat flow are solved on an hourly basis and summed over the period of one day. Evapotranspiration is calculated at the end of the day and the change in water content (θ) is updated at the beginning of the next day. This modification of the Priestley-Taylor equation allows for the soil-water content to limit evapotranspiration. If moisture conditions change due to precipitation then α' approaches 1.26 allowing evapotranspiration to approach the equilibrium evaporation rate.

It is important to note that runoff, not net infiltration, is calculated as the solution to the water-balance equation. A unit gradient is assumed and net infiltration is incorporated in the water-balance formulation as a temporary potential net-infiltration term and is limited by the field-scale-saturated hydraulic conductivity of the soil or bedrock underlying the root zone.

The net-infiltration modeling process requires a combination of applications using Geographic Information System (GIS) applications, field measurements (or acquisition of existing field data), parameter estimation, visualization and analysis, and the application of developed FORTRAN codes. The FORTRAN codes are used for pre-processing model input, the implementation of process modeling using INFIL V2.0 for simulating net infiltration, and for post-processing of model results, which includes the development of net-infiltration estimates for a given climate scenario by averaging separate model simulation results. The process modeling for net infiltration consists primarily of an hourly energy balance and a daily water balance simulation for a continuous multi-year period. The daily net-infiltration rates are averaged over the duration of the simulation for each model node to obtain spatially distributed, time-averaged net-infiltration rates.

3.1.2 Accuracy and Precision of Model Calculations

The simulation of net infiltration primarily involves a water-balance calculation and the application of the conservation of mass principle. All water-balance calculations are performed as water-depth balances (which are easily converted to volume balances[1]), and thus an assumption is made that calculation errors due to temperature effects on water density are negligible relative to the level of precision needed for net-infiltration estimates.

[1] Model calculations are performed as water-depth balances, and are converted to volume balances based on model grid cell area, which is 900 square meters for all model grid cells.

Model calculations are performed using double precision variables and standard FORTRAN77 programming language. The model code performs several internal mass balance checking calculations that are used to test the precision of the overall water-balance simulation (program testing and software validation are described thoroughly in the software qualification documentation). For estimated average annual net-infiltration rates, model results are provided for each model grid cell to the nearest 0.00001-millimeter (mm) water depth for all components of the water balance to allow for additional mass-balance checking using post-processing procedures. This level of internal precision does not indicate the level of expected precision in model results. Based on the average number of significant figures in model input, the number of significant figures that can be applied to model results should not exceed two. This degree of output precision is subjectively based on the average level of precision in model inputs.

3.2 CONCEPTUAL MODEL OF INFILTRATION

The conceptual model defines net infiltration as water that has percolated from the land surface to below the root zone. The root zone herein is defined as the zone from the ground surface to some variable depth in soil or bedrock from which infiltrated water is readily removed on an annual or seasonal basis by evapotranspiration. The depth of the root zone can be estimated from field studies but cannot be defined precisely. In addition, the depth of the root zone depends on variable climate and surface conditions controlling vegetation and other factors affecting evapotranspiration and is thus transient and spatially variable. Infiltration is the movement of water across the air/soil or air/bedrock interface, and percolation is defined as the downward movement of water within the unsaturated zone.

The current conceptual model of infiltration at Yucca Mountain identifies effective precipitation, which is the ratio of precipitation to potential evapotranspiration, as the most significant environmental factor controlling net infiltration at Yucca Mountain. Precipitation averages 170 mm/yr over the study area but is temporally and spatially variable (Hevesi et al., 1992). On an annual basis effective precipitation is low because potential evapotranspiration is much higher than precipitation. However, on a daily basis, effective precipitation can be high, particularly during periods with large and frequent winter storms. For example, the average penetration depth of infiltration[2] into the soil/bedrock profile fluctuates on a seasonal basis for a given location, but tends to be greatest in the winter due to lower evapotranspiration demands, higher amounts of precipitation, and slow snow melt.

The second most significant environmental factor controlling net infiltration is soil depth. When there is sufficient precipitation to produce net infiltration, the spatial distribution is generally defined by the spatial variability of soil depth. Field measurements indicate that when the soil/bedrock contact reaches near-saturated conditions (see Figure 6-6A), fracture flow is initiated in the bedrock (as evidenced by changes in water content profiles), increasing the hydraulic conductivity by several orders of magnitude. Soils exceeding 6 meters in thickness eliminate the infiltration of water to the soil/bedrock contact except in channels (Flint and Flint, 1995). Storage capacity in the soil profile is large enough that most water from precipitation is held in the root zone and removed by evapotranspiration processes. Soils that are less than 6 meters deep do not have enough storage capacity to store the volume of precipitation, and often allow near-ponding conditions to occur at the soil/bedrock contact, particularly when the soil depth is less than 0.5 meters.

[2] The penetration depth of infiltration is identified by the maximum depth at which a wetting front is observed based on geophysical logs.

The third factor controlling net infiltration is bedrock permeability. At Yucca Mountain welded tuffs of the Tiva Canyon welded (TCw) hydrogeologic unit, and nonfractured, nonwelded tuffs of the Paintbrush nonwelded (PTn) hydrogeologic unit are the principal rock types present in surface exposures or directly under soils. The saturated hydraulic conductivity of the nonwelded PTn matrix is higher than the TCw matrix (Flint, 1998, Table 7). The fractures in the welded tuff increase the saturated hydraulic conductivity of those rocks but due to channeling and the presence of inactive as well as active fractures (Liu et al., 1998), the unsaturated bulk conductivity is generally not more than that of the matrix of the nonwelded tuffs. The lower storage capacity of the fractured, welded tuffs allows moisture that has infiltrated to penetrate more deeply than in the nonwelded tuffs. Hydraulic properties of fractures calculated for this study depend on fracture aperture and whether or not the fractures are open or filled with calcium carbonate or siliceous materials. Based on numerical simulations of water flow through a block of variably saturated fractured tuff, Kwicklis et al. (1998, p. 60) suggest that the infiltration of water into a fractured welded tuff, such as the TCw, will be controlled by the water potential at the soil-bedrock interface. Because the apertures and the air-entry water potentials of unfilled fractures (Kwicklis et al., 1998) are larger than the overlying soils, the initiation of fracture flow should occur only under saturated or near-saturated conditions. Fracture densities and matrix permeabilities are variable among the geologic units at Yucca Mountain.

Shallow infiltration processes at Yucca Mountain can be described on the basis of four infiltration zones that can be identified based on the manner in which volumetric water content changes with depth and time (Flint and Flint, 1995). The zones, which correlate with topographic position, are described as follows: (1) Ridgetops are flat to gently sloping, of higher elevation than the other zones, and have thin soils composed of both eolian deposits and soils developed in place from the weathering process. These soils often have higher clay content and higher water-holding capacity compared to soils on sideslopes and alluvial terraces. The ridgetops generally are located where the bedrock is moderately to densely welded and fractured. The presence of thin soil and fractured bedrock results in the deeper penetration of moisture following precipitation compared to other topographic positions. In some locations where runoff is channeled, large volumes of water can infiltrate. For the present-day arid climate, runoff generally is restricted to the upper headwater portions of drainages and to locations downstream of areas that have very thin soils underlain by relatively impermeable bedrock. (2) Sideslopes are steep, commonly have thin to no soil cover, and are usually developed in welded, fractured tuff. The steepness of the slopes creates conditions conducive to rapid runoff. The low storage capacity of the thin soil cover and the exposure of fractures at the surface may enable small volumes of water to infiltrate to greater depths, especially on slopes with north-facing exposures and therefore lower evapotranspiration demands. Shallow alluvium at the bases of the slopes can easily become saturated and initiate flow into the underlying fractures. (3) Alluvial terraces are flat, broad deposits of layered rock fragments and fine soil with a large storage capacity. Little runoff is generated on the terraces and the precipitation that falls there does not move below a depth of one to two meters before it is removed evapotranspiration. Consequently, this zone contributes the least to net infiltration in the drainage basin. (4) Active channels are similar to the terraces but are located in a position to collect and concentrate runoff that, although occurring infrequently, can penetrate deeply. Although local net infiltration can be high for some channel locations, under the current arid climate this mechanism is not considered a major contributor to the total volume of net infiltration at Yucca Mountain, because runoff is infrequent and because the channels areas include only a very small percentage of the total drainage basin area.

3.3 HYDROLOGIC CYCLE

In the conceptual model, the hydrologic cycle is used to identify, define, and separate the various field-scale components and processes controlling net infiltration (Figure 3-1). The hydrologic cycle is a basic conceptual tool used to visualize and define the various components of the field-scale water balance (Maidment, 1993, Figure 1.2.1, p. 1.4; Freeze and Cherry, 1979, Figure 1.1, p. 3). The hypothetical starting point of the hydrologic cycle is precipitation, which for current (modern) climate at Yucca Mountain occurs primarily as rain but can also occur as snow. Precipitation can accumulate on the ground surface,[3] infiltrate the soil or exposed bedrock[4] surfaces, contribute to runoff, or accumulate as snow. The contribution of precipitation to runoff generation depends on precipitation intensity relative to soil and exposed bedrock hydraulic conductivity, and also on the available storage capacity of soil and shallow bedrock with thin or no soil cover. Water accumulated in the snow pack can sublimate into the atmosphere or become snowmelt, which can then infiltrate, evaporate, or contribute to runoff. Rain or snowmelt that becomes runoff accumulates in surface depressions and basins or contributes to surface water flow, which is routed to downstream locations as run-on.[5] Run-on contributes to either infiltration or accumulated surface-water run-on at downstream locations. Infiltrated water percolates through the root zone as either saturated or unsaturated ground water and is subject to evapotranspiration. Water percolating through the root zone is available as potential net infiltration, but the actual net-infiltration rate is limited by the bulk (or field-scale) saturated hydraulic conductivity of the bedrock or soil underlying the root zone. In the conceptual model, the bulk saturated hydraulic conductivity represents a weighted averaging of the field-scale matrix and fracture saturated hydraulic conductivity. Estimates of saturated hydraulic conductivity were calculated using these measured values of fracture conductivity for the percentage of area covered by the fracture per square meter of rock, given the fracture density and aperture size available for water to flow through. This was added to the saturated hydraulic conductivity of the rock matrix and weighted averages of bulk saturated hydraulic conductivity of bedrock, on the basis of percentages of matrix and fractures, were calculated by lithostratigraphic unit (see Appendix 1-C, B, Part 2). When infiltration from rain, snowmelt, or surface-water run-on occurs at a rate greater than the bulk saturated hydraulic conductivity of a subsurface layer, water will begin to fill the available storage capacity of the overlying soil. When the total storage capacity is exceeded, runoff is generated. While runoff can occur while the subsurface is still unsaturated due to precipitation exceeding the saturated hydraulic conductivity of the soil, this is on a small scale, and irrelevant to modeling of 30m x 30m grid blocks.

Figure 3-1. Field-scale water balance and processes controlling net infiltration. (Appendix 3)

[3]Some precipitation can also be intercepted and temporarily stored by vegetation surfaces, but this component of the hydrologic cycle is negligible at the study site.
[4]In this report, bedrock is used as a general term referring to all consolidated rock material that is either exposed (outcropping) or overlain by unconsolidated soil material.
[5]In this report, runoff is specifically defined as the volume or depth of water accumulation on the ground surface prior to being routed as surface-water flow, whereas run-on is defined as the volume or depth of the routed surface-water flow.

In the Yucca Mountain area, the hydrologic cycle can be limited to atmospheric, surface, and shallow sub-surface processes because contributions from ground water discharge and the deep unsaturated zone are insignificant relative to the other components of the cycle[6] (there is no perennial stream flow at the site).

3.3.3 Evapotranspiration

Evapotranspiration is the combined process of bare-soil evaporation and transpiration (excluding evaporation from open water bodies) (Freeze and Cherry, 1979, p. 4). Transpiration is the uptake and transfer of water to the atmosphere by vegetation. Transpiration is much more efficient than bare-soil evaporation in removing water from sub-surface soils and fractured bedrock. Evapotranspiration is a function of the potential evapotranspiration rate, the availability of water at the ground surface and within the root zone, vegetation characteristics such as timing of plant growth and root density, and the chemical and hydrologic properties of the root zone. The processes are not independent, but in general the primary factors controlling evapotranspiration are potential evapotranspiration, water availability, vegetation density, and seasonal vegetation growth. The more saturated the soil (or fractured bedrock) and the denser the vegetation, the closer the transpiration rate is to the potential evapotranspiration rate. If the soil (or fractured bedrock) becomes drier than what is conceptually referred to as the wilting point, transpiration will not occur even though there may be some residual water in the root zone. The redistribution of water within the root zone affects the total evapotranspiration rate because bare-soil evaporation extends approximately depths of only 10 to 30 cm, and the density and growth of roots within the root zone in general is typically observed to decrease with depth. The estimate of the depth of bare-soil evaporation is based on field measurements of water potential with depth. At above about 20-30 cm the water potential values are too dry for extraction by plant roots. The more quickly water redistributes to lower depths the greater the potential for net infiltration to occur because the overall susceptibility of water in the root zone to removal by evapotranspiration decreases with depth. At depths greater than the root zone vapor flow and matric suction potentials can result in upward unsaturated flow or exfiltration back into the root zone; but total water losses from these processes are considered negligible relative to evapotranspiration within the relatively thin root zone.

The potential evapotranspiration rate is determined by the energy balance and depends primarily on net radiation, air temperature, ground heat flux, the slope of the saturation-vapor density curve, and advective energy from wind (McNaughton and Spriggs, 1989; Priestley and Taylor, 1972; Flint and Childs, 1991). Net radiation depends primarily on solar radiation and surface characteristics including topography and albedo. For the current climate at Yucca Mountain, the average annual potential evapotranspiration rate is approximately six times greater than the average annual precipitation rate (Hevesi et al., 1994b, p. 2326); thus, on an annual basis, most of the precipitation is removed from the site by evapotranspiration. However, on a daily basis, the precipitation, snowmelt, or surface-water run-on rate, can be much higher than the potential evapotranspiration rate, especially during the winter when the potential evapotranspiration rate is at a minimum.

[6] Vapor flow enhanced by barometric pumping and temperature gradients also contributes to the water balance at the site but has been shown to be insignificant relative to precipitation, evapotranspiration, runoff, and net infiltration.

3.3.4 Net Infiltration

Net infiltration at Yucca Mountain is dominantly an episodic process that tends to occur only under wetter than average conditions or in response to isolated but intense storms (Flint et al., 1996; Flint and Flint, 1995; Hevesi et al., 1994a). For upland areas having thin soils and rooting depths, the occurrence of net infiltration requires saturated or near-saturated conditions at the soil/bedrock interface and within shallow bedrock fractures to initiate flow through open or filled fractures (see Section 6.1.2). Assuming that active roots can extend into bedrock along open or partially filled fractures, a maximum effective rooting depth of approximately two meters is estimated for fractured bedrock, with a much lower root density and water storage capacity relative to soils. For locations with thick soils, the occurrence of net infiltration requires percolation through a deeper average rooting depth that is estimated to be approximately 6 meters (Flint et al., 1996; Flint and Flint, 1995).

For larger storm or snowmelt events, water can accumulate in the root zone more rapidly than it can be removed by evapotranspiration. This is especially true during winter when potential evapotranspiration is at a minimum due to shorter days, lower sun angle, and lower air temperatures and root activity is either diminished or dormant. The downward percolation rate through the root zone under these conditions depends primarily on the storage capacity of the root zone and the field capacity and hydraulic conductivity of the soil and bedrock. The total storage capacity of the soil is defined as the porosity minus the residual water content multiplied by the soil depth. Field capacity is defined as the water content of the near surface soil profile (i.e., the root zone) at which drainage becomes negligible (several orders of magnitude less than the saturated flux rate) (Jury et al., 1991, p. 150). Field capacity is an old soil physics concept intended to provide a characteristic index of how much water may be retained from a rainfall event after redistribution has ceased. In actual field conditions, water drains continually under gravity. However, in coarse-textured soils such as those found at Yucca Mountain, the drainage rate falls to an insignificant level within a few days, after which the water content is changing at such a slow rate that a field capacity concept has practical value (Jury et al., 1991, p. 150). In skeletal soils found in southwestern Oregon, the water content at a measured mean value of -0.07 bars for field capacity was obtained (Flint and Childs, 1984). Flint and Childs (1984) argued that the water content at close to –0.1 bars was more appropriate for field capacity than the assumption of –0.33 bars that was commonly used, based on soil textures common to agricultural fields. This publication and other large scale studies conducted in major metropolitan water districts in southern California and regional watershed studies in Japan, provide support for the use of the field capacity concept in the gravelly sandy soils located at Yucca Mountain. For thick soils, reaching or exceeding field capacity at a depth of 6 meters tends to occur only for locations subject to concentrated surface-water flow, such as active stream channels and the base of steep sideslopes. For upland areas with thin soils, the percolation rate through the root zone depends on the field-scale storage capacity, and once exceeded, the hydraulic conductivity of bedrock. Thus, the effective field capacity of the root zone in upland areas is determined by bedrock lithology, fracture characteristics (density, aperture, filling), and the characteristics of the soil/bedrock interface, in addition to the characteristics of the overlying soil. The water potential that corresponds to the volumetric water content measured at field capacity is considered to be –0.1 bars and is shown for the soils used for modeling infiltration at Yucca Mountain in Appendix I-C.

Two exercises are conducted to illustrate the negligible value of drainage at water contents below the field capacity value of –0.1 bars. Using values of soil properties listed in Appendix 1-C, Table A1-6, unsaturated hydraulic conductivity was calculated for soils with average water potentials at 0.025 bars, -0.1 bars (field capacity), and -0.5 bars. At 0.025 bars the unsaturated hydraulic conductivity is reduced about 2 orders of magnitude below that of the saturated hydraulic conductivity, with a value of 10.7 mm/day. At field capacity the rate drops to 4 orders of magnitude, with an unsaturated hydraulic conductivity of 0.25 mm/day. Once below field capacity, at 0.5 bars, the rate drops to 6 orders of magnitude, which is 0.003 mm/day. As the evapotranspiration rate at about –0.2 bars is approximately 2-3 mm/day, the soil dries quickly to very low drainage rates.

A calculation of drainage for measured soil water contents was done for a borehole located in an active channel, illustrating relatively wet conditions. For borehole N1, located in Pagany Wash where the channel is about 3 m in cross-section, and the soil is 8.3 m deep, drainage from the soil was calculated as the unsaturated hydraulic conductivity at an average volumetric water content from below an estimated zone of evapotranspiration, 3 m, to the bottom of the alluvium. For monthly measurements made for the period of 1984 through 1995, the drainage was calculated to be 0.5 mm/yr in this active channel with periodic runoff. Flux was calculated as described in Section 6.3.4 for this borehole, using the average water content for 2 m of soil below 6 m in depth. Increases in average water content between monthly measurements were summed for values that were greater than the measurement error of 0.006 m^3/m^3. The total flux calculated for the 10 year period was 83.5 mm/yr (when distributed over a 30 m grid cell, this equates to about 10 mm/yr.). The drainage due to gravity from the soil for this borehole was 0.6% of the total flux calculated for the borehole. Boreholes located in topographic locations where runoff is unlikely, such as terraces, have soils that are generally much drier, potentially reducing the drainage by several orders of magnitude below that calculated for this borehole. As the net infiltration flux calculated in these locations also is much lower, the contribution of drainage to the total flux in the borehole would be higher, but the drainage, even at somewhat moist ranges of between –1 bar and –5 bars, the drainage ranges from 0.2 mm/yr to 0.001 mm/yr.

In general, the volume of net infiltration occurring at Yucca Mountain under conditions of unsaturated ground-water flow when the root zone is drier than field capacity either in upland areas with thin soils or in locations with thick soils is considered negligible compared to the volume of net infiltration occurring as saturated flow through bedrock fractures or through thick soils that have reached or exceeded field capacity (Flint et al., 1996; Flint and Flint, 1995; Hevesi et al., 1994b; Nichols, 1987).

4. ASSUMPTIONS, CONSTRAINTS, BOUNDS, AND LIMITS

The assumptions pertaining to use of INFIL V2.0 are grouped according to the following types of investigations conducted: (1) development of the conceptual model of net infiltration, (2) development of the numerical model of net infiltration, (3) model calibration and comparison to independent methods, and (4) development of estimated input parameter distributions and climate inputs in support of the net infiltration uncertainty analysis documented in CRWMS M&O (2000b).

The numerical representation of the conceptual model depends on the assumption that simplification of physical processes characterized by the conceptual model can be achieved while maintaining a sufficient level of accuracy in the mathematical approximation of these physical processes. This assumption is supported, in part, by model calibration and model validation.

It is assumed on the basis of numerous YMP peer reviews and several publications (e.g. Hatton, 1998, pp. 5-7, 16), that the use of INFIL V2.0, which uses a distributed parameter, quasi-three-dimensional water-balance approach, and associated assumptions, is appropriate for the complexity of this analysis of net infiltration and is relevant in this large-scale application of providing the upper boundary condition to the UZ flow and transport model. It is noted that this approach does not necessarily represent the physics of infiltration in soils, but uses a water volume calculation approach in the mathematical and numerical models. This model has been compared successfully to several independent approaches to estimating net infiltration and recharge, and more rigorous methods based, for example, on detailed numerical solution of the differential equations of ground-water and surface-water flow are not feasible for use in this large-scale application.

The infiltration model and analysis are based on the assumption that the 1996 infiltration model, which was based on the distributed-parameter, water-balance approach and was calibrated using a variety of field data collected from 1984 through 1995, adequately represents the major features and processes controlling present-day and future infiltration at Yucca Mountain. The principal basis for the assumptions, discussed below, is that the resulting net-infiltration model quantitatively accounts for all major water inflow and outflow processes on a cell-by-cell basis and strictly imposes the conservation of total water mass within each model cell. The calculation results do not account for error propagation from the various components of the mass balance, such as measurement error associated with the various model inputs.

Within each cell of the model domain, water is assumed to move vertically downward within soil and bedrock, and that on a 30m x 30m grid block basis, there is no lateral diversion within the root zone. This is a viable assumption based on several calculations of specific conditions at the site. Given a land surface slope of approximately 4 to 6 degrees, the sine of the gravity vector is 0.07 to 0.10. The saturated hydraulic conductivity of the alluvium is 5.6E-6 m/s to 6.7E-6 m/s and the porosity is 35 percent. Using Darcy's equation and assuming fully saturated flow in a lateral downslope direction, with a perched system at the bedrock/alluvium contact that parallels the soil surface, the distance that lateral flow would travel in 30 days is approximately 3 to 6 m, thereby not moving beyond the 30m x 30m grid block area. If the slope were 45 degrees, the distance would be an order of magnitude greater. According to Hatton (1998), 1-dimensional, distributed-parameter, water-balance models are appropriate for use unless the excess rainfall generates overland flow (which is accommodated by flow routing in INFIL V2.0), or with the development of saturated conditions in soil profiles on slopes. The above calculation, and the fact that slopes have very thin soil cover and the underlying fractured bedrock has a high saturated hydraulic conductivity, negate this as a significant concern. On the other hand, if water were to move from one grid block downslope to the next grid block at the soil/bedrock contact, in a three-dimensional model configuration, this volume would be additive and would continue downslope until the slope was reduced, resulting in a shorter lateral travel distance. The total slope would only be affected in the uppermost and lowermost grid blocks. This component of error is considered to be insignificant relative to the spatial resolution required for the site-scale UZ ground water flow model.

Net infiltration is assumed to occur as fracture flow through the Tiva Canyon welded hydrogeologic unit (TCw) that is considered within the root zone. This assumption is based on relative changes in measured water content profiles that indicates that the penetration rates of the wetting front exceeded that calculated from the saturated hydraulic conductivity of the matrix alone. An assumption is also made that saturated fracture flow is maintained only for the duration that saturated conditions are maintained along the soil-bedrock interface. This assumption is based on interpretations of relative changes in the time series of water content profiles measured in boreholes by neutron logging (Flint and Flint, 1995), and corresponding nearby measurements of water potential at the soil/bedrock contact indicating saturated or near saturated conditions. The net infiltration rate for the time periods when net infiltration is occurring is assumed to be numerically equivalent to the bulk saturated hydraulic conductivity of the bedrock. This model does not use pressure gradients to induce flow and does not consider positive pressure heads.

The evapotranspiration coefficients given in DTN: GS000300001221.009 are assumed to be representative of conditions at Yucca Mountain. The values used (alpha for saturated surfaces (1.26) and bare soil surface (1.04) and B (-10)) are based on measurements at other locations and are commonly used and regarded as appropriate within the scientific community (Priestley and Taylor, 1972 and Flint and Childs, 1991).

The stream-flow routing algorithm is not an approximate solution to the governing partial differential equations of surface water flow (various forms of the St. Venant equations). Kinematic and inertia effects, flood waves and backwater effects are not being modeled. Additional factors not being considered are density changes due to temperature changes throughout the water profile, gravitational acceleration, resistance terms, viscosity changes due to sediment load, phase changes, changes in fluid hydraulics due to shifts from turbulent to laminar flow, flow dispersion and dynamic shifts in channel geometry due to concurrent stream bed erosion and deposition. The only physical process being represented by this model is the lateral redistribution and subsequent infiltration of the runoff water volume and it is assumed that this can be adequately modeled based on elevation alone. In addition, the details of positive heads in active channels are insignificant relative to the uncertainty of available input parameters required to accurately define stream channel geometry for the entire stream channel network represented by this model.

It is assumed that changes in liquid properties, such as viscosity and density, on the saturated field-scale hydraulic conductivity of soil and bedrock are insignificant. This assumption is justified because temperature variations in the near-surface environment that could affect the viscosity or density of water are expected to be small and because dissolved constituents that could affect the density of water are expected to be present in insignificant concentrations.

While there is evidence that there is negligible downward flow occurring during long time-periods of no precipitation, it is included as an assumption. Very small changes in volumetric water content cannot be measured using neutron logging, which assumes that changes less than 0.006 m^3/m^3 are within the error of the measurement. Drainage under a unit gradient during time periods when soil water content is below field capacity can be calculated and an example is included in Section 6.1.5.

Model uncertainty is being addressed through parameter input distributions that are being developed as a part of the net infiltration model uncertainty analysis (CRWMS M&O 2000b). Input distributions are developed for 12 selected parameters (estimated a-priori as being potentially significant) from those included in the model control file. The developed distributions are based on assumptions of upper and lower bounds for each of the selected parameters. Additionally, the distribution type for each selected parameter is assumed. CRWMS M&O (2000b) should be consulted for complete documentation of the assumptions and their bases.

5. MODELING PROCEDURE

5.1 DISTRIBUTED-PARAMETER WATER-BALANCE MODEL

The distributed-parameter, water-balance model developed as the FORTRAN program INFIL V2.0 follows the conceptual model of infiltration discussed in Section 3.0, and is represented using a storage volume approach for modeling the root-zone. The total root-zone water storage capacity is calculated using the 30m x 30m area of each grid cell multiplied by the depth of the root-zone (including soil and bedrock layers) . The root-zone water balance calculation used to model net infiltration is illustrated by Figure 5-1. Infiltration into the root-zone and net infiltration through the root-zone is calculated independently for all grid cells and corresponding root-zone storage volumes. Because all grid cells have equal areas, the root-zone water storage terms are calculated as 1-dimensional vertical storage depths, which can easily be converted to volumes based on grid cell areas. The components of the root-zone water balance are determined for each layer using the water content of each layer. For water contents less than or equal to the water content at field capacity, infiltration is set to zero and water loss due to evapotranspiration from that layer is modeled as an empirical function of relative saturation (with relative saturation based on porosity and the residual water content) and potential evapotranspiration (Flint and Childs, 1991). For water contents greater than the water content at field capacity, water losses due to both infiltration and evapotranspiration from the layer are calculated. Infiltration into the underlying layer is set equal to the bulk saturated hydraulic conductivity of that layer (in millimeters per day). If the available water for net infiltration (calculated based on the amount of water remaining after evapotranspiration losses have been calculated) is less than the maximum infiltration amount determined using saturated hydraulic conductivity, water loss to infiltration is set equal to the amount of available water in the layer. For the lowermost root-zone layer in thick (6 meters or greater) soils, the daily water loss to infiltration is used to determine net infiltration. For upland areas with shallow soils where the root-zone is modeled as having a lowermost layer in bedrock, the amount of water available to evapotranspiration losses is calculated using the fracture porosity and the thickness of the bedrock layer. Once the water content of the bedrock layer has reached the limit defined by the fracture porosity, if water continues to infiltrate or percolate into the bedrock layer, net infiltration is calculated based on either the saturated hydraulic conductivity of the bedrock layer or the amount of available water (whichever determines the lower net infiltration amount).

On a daily basis, precipitation, snowmelt, and surface water run-on are added (as water depth) to the top layer of the root-zone profile at each grid cell. The surface water run-on depth is calculated as runoff generated and routed from upstream grid cells. If the amount of precipitation, snowmelt, and run-on added to the top layer exceeds the maximum daily amount calculated using the saturated hydraulic conductivity of the soil, then runoff (set equal to the amount of excess water) occurs at that grid cell location and is routed to the downstream grid cell. Surface-water flow depths are routed as part of an instantaneous flow routing algorithm representing a daily water balance. All overland flow is routed as a time-independent flow depth for each grid cell within a 24-hour time step (the physics of overland flow are not considered in this type of model). Daily surface water flow volumes are calculated using grid cell areas and converted to standard stream discharge units (cubic-feet-per-second) for comparison with measured stream flow records.

For locations where the lowermost root-zone layer is in bedrock, net infiltration is numerically equal to the bulk saturated hydraulic conductivity of the underlying bedrock (in millimeters/day) for the period of time where the water content of the lowermost root-zone layer exceeds the field capacity of that layer.

Net infiltration is simulated as the bulk saturated hydraulic conductivity of the underlying bedrock when the water content of the bedrock root-zone layer equals the fracture porosity of that layer. This condition is maintained only as long as the field capacity of the bottom soil layer (the soil layer above the bedrock layer) is exceeded. Thus, for upland areas with shallow soils, net infiltration is simulated as an episodic process requiring saturated conditions at the soil/bedrock interface and throughout the effective flow path of the bedrock layer included in the root-zone.

For locations with thick (greater than 6 meters) soil, net infiltration does not require saturated conditions at the bottom of the root zone, but does require that the water content of the bottom soil layer exceeds the field capacity of the layer. For upland areas, it is assumed that water ponded at the soil/bedrock interface and saturating the effective flow path through the bedrock root-zone layer percolates below the root-zone as net infiltration on a daily basis under a unit gradient. In all cases, water losses due to evapotranspiration are simulated for all root zone layers having a water content greater than residual prior to the calculation of net infiltration. During winter when potential evapotranspiration is at a minimum, ponded or saturated conditions at the soil/bedrock interface and throughout the effective flow path of the bedrock root-zone layer may exist for several days. Thus the total net infiltration is calculated as approximately the saturated hydraulic conductivity multiplied by the number of days net infiltration occurred. For days when the amount of water available for net infiltration is less than the limit set by the saturated hydraulic conductivity of the bedrock (this condition applies only to the last day of an extended net infiltration event), net infiltration equals the amount of water available to net infiltration in the lowermost root-zone layer.

The daily water balance model is applied over a continuous multi-year period and is driven by the continuous daily climate input provided for the total simulation period. The daily net infiltration rates calculated for each grid cell location are used to calculate an average annual net infiltration rate for each grid cell based on the total simulation period. The average annual net infiltration rate is calculated in units of length per time (millimeters per year), and can be directly applied as a specified flux upper boundary condition for the UZ flow and transport model.

Figure 5-1. The daily root-zone water-balance used to model net infiltration. (Appendix 3)

5.2 MODELING PROCESS

The net infiltration modeling process begins with building a geospatial input parameter base grid using the selected digital elevation model (DEM) to define the base-grid geometry. The development of the geospatial input parameter base grid and the separate watershed modeling domains requires the application of Geographic Information Systems (GIS) to transfer available digitized map data, which is in a vector-based format, onto the grid-cell of the raster-based format of the DEM (a process referred to as rasterization). The vector-based map coverages used as input by the net infiltration model include bedrock geology and soil type maps. In addition to the rasterization procedure, GIS applications are also used for calculating slope and aspect as well as latitude and longitude coordinates for all grid cells. Geospatial parameters that are not available as either raster-based or vector-based map coverages are developed using a series of FORTRAN routines that are applied sequentially. The routines are used to overlay three separate bedrock geology maps (after rasterization), estimate soil thickness, calculate the blocking ridge parameters, calculate surface water flow routing parameters, and extract the watershed model domains.

The DEM (DTN: GS000308311221.006) selected for defining the grid geometry is the composite DEM used for the original net infiltration model (Flint et al., 1996) that was developed from two standard USGS 7.5 minute 30-meter DEMs (Busted Butte and Topopah Spring NW). The two DEMs (DTN:GS000200001221.003) were combined into a composite DEM (DTN: GS000308311221.006) by using the ARCINFO, ARC-EDIT, ARC-PLOT, and ARC-GRID modules, utilizing a series of standard commands within the various modules. The grid geometry of the composite DEM (DTN: GS000308311221.006) is based on the Universal Transverse Mercator (UTM) projection (zone 11, NAD27) and consists of 691 rows in the north-south direction and 367 columns in the east-west direction covering a rectangular area centered over Yucca Mountain and the potential repository site, with the following corner coordinates:

Northwest corner:	544,661 meters easting, 4,087,833 meters northing
Northeast corner:	555,641 meters easting, 4,087,833 meters northing
Southeast corner:	555,641 meters easting, 4,067,133 meters northing
Southwest corner:	544,661 meters easting, 4,067,133 meters northing

The elevation provided by the composite DEM (253,597 values) is the primary geospatial parameter used by the net infiltration model. Elevation is used to define the surface-water flow-routing network, which is in turn used to define watershed-modeling domains which are extracted from the base grid and modeled separately as closed hydrologic systems. Elevation is used to define slope, aspect, and blocking ridge parameters for modeling incoming solar radiation that is in turn used in an energy balance calculation for modeling potential evapotranspiration. The calculated slope is also used to model soil thickness. Additional uses of elevation values in the net infiltration model include estimation of spatially distributed daily climate input (precipitation and air temperature).

In addition to the geospatial input parameters, the daily climate input and the model parameter inputs are defined prior to application of the net infiltration model. Daily climate input includes precipitation and air temperature. Model parameters include soil properties, bedrock properties, and root-zone parameters. An initial condition consisting of the root-zone water content is also defined prior to model application. Following the development of the base grid, the following 11 steps summarize the net-infiltration modeling procedure used for this analysis:

1. Acquisition and/or development of GIS map coverages and the application of ARCINFO V6.1.2 (USGS 2000) for the rasterization of geospatial parameters onto the base grid defined by the digital elevation model (DEM) for Yucca Mountain. Conversion of grid cell coordinates to both UTM zone 11 and geographic (latitude and longitude) using ARCINFO V6.1.2.

2. Calculation of topographic parameters, including grid cell slope and aspect using ARCINFO V6.1.2, and 36 blocking-ridge angles for each grid cell using the routine BLOCKR7 V1.0 (the blocking-ridge angles used in the geospatial-parameter input file for INFIL V2.0 are the same as those used in the input file for the 1996 INFIL V1.0 model).

3. Estimation of soil depth and refinement of bedrock geology (rock-type identification) using the programs GEOMAP7 V1.0, GEOMOD4 V1.0, and SOILMAP6 V1.0.

4. Calculation of surface-water flow routing parameters for each model grid cell using the DEM and the programs SORTGRD1 V1.0 and CHNNET16 V1.0.

5. Identification of watershed outflow locations using TRANSFORM[7] V3.3 for raster data visualization and output from CHNNET16 V1.0. Extraction of watershed modeling domains, including calibration modeling domains, using the DEM, the identified outflow locations, the calculated surface-water flow-routing parameters, and the program WATSHD20 V1.0.

6. Development of a daily climate input file (mod3-ppt.dat) for model calibration and modern climate simulations using available precipitation records from monitoring sites within the study area and in the proximity of Yucca Mountain. Development of mod3-ppt.dat is performed within an EXCEL spreadsheet (mod3-ppt.xls) using a linear interpolation method.

7. Estimation of pre-calibration model coefficients and initial conditions for root-zone water contents.

8. Calibration of root-zone model coefficients included as input in model control file for modeling program INFIL V2.0 by comparing simulation results for calibration watersheds against streamflow records.

9. Development of 100-year daily climate input files for modern climate scenarios using available precipitation records from the Nevada Test Site stations 4JA and Area 12 Mesa and the programs MARKOV V1.0 (STN 10142-1.0-00) and PPTSIM V1.0. (STN 10143-1.0-00) Development of daily climate input for future climate scenarios using the routine DAILY09 V1.0 and seven selected analog records from the EARTHINFO[8] database.

10. Application of INFIL V2.0 (STN 10307-2.0-00) using developed daily climate input (mod3-ppt.dat, 4ja.s01, area12.s01, nogales.inp, hobbs.inp, rosalia.inp, spokane.inp, stjohn.inp, beowawe.inp, and delta.inp), calibrated or estimated root-zone model coefficients, and watershed modeling domains for net-infiltration simulations.

INFIL V2.0 output is used to develop net-infiltration estimates for nine separate climate scenarios by averaging or sampling from individual net-infiltration simulations using the routine MAPADD20 V1.0. Output also is used to development of descriptive statistics for results over the areas of the potential repository boundary and the UZ flow and transport-modeling domain and development of model results as GIS coverages.

6. MODEL COMPONENTS

6.1 OVERVIEW

The INFIL V2.0 model algorithm consists of three main loops for performing a daily simulation of net infiltration over all model cells comprising a watershed model domain. Figure 6-1 provides a generalized illustration of the various model components required for simulating spatially distributed net-infiltration rates.

Figure 6-1. Major components of the net-infiltration modeling process. (Appendix 3)

[7] TRANSFORM is a registered trademark of Fortner Software LLC, 100 Carpenter Dr, Sterling, VA 20164.
[8] EARTHINFO is a registered trademark of EarthInfo Inc., 5541 Central Avenue, Boulder, CO 80301.

Figure 6-2. Flow chart of the model algorithm used for simulating net infiltration (Appendix 3).

Figure 6-2 provides a flow chart illustration of the general model algorithm and the primary loop (day-of-year loop), which is driven by the daily climate input file and carries the simulation through the time domain. Nested within the primary loop is a grid cell loop for performing a daily water balance calculation at each grid cell location and within each layer of the root zone. [The root zone was subdivided into layers based on the estimated maximum depth of bare-soil evaporation and an estimated variation in root density. In general, the layering represents a decrease in root density with increased depth in the root zone, particularly at locations with thick soils (greater than 6 meters).] The daily root-zone water balance consists of simulating precipitation, snowmelt, sublimation, evapotranspiration, changes in water content for each root-zone layer, net infiltration, and runoff generation. Nested within the water-balance loop is an hourly loop for modeling potential evapotranspiration based on the simulation of incoming solar radiation and effects on total solar radiation due to blocking ridges using the SOLRAD sub-model and the routine BLOCKR7 (Flint et al., 1996; Flint and Childs, 1987).

After the completion of the water-balance loop, a surface-water flow-routing subroutine is called if runoff was generated at any grid cell. Surface-water flow is routed at the end of the day as a time-independent (instantaneous) total daily flow depth across each grid cell. The routing algorithm connects all grid cells horizontally using surface-water flow-routing parameters included in the geospatial parameter input file. Surface-water flow is coupled to the water-balance calculation by allowing surface water to infiltrate into downstream grid cells according to the available root-zone storage capacity, soil hydraulic conductivity, and estimates for effective surface-water flow area and stream flow duration. The infiltrated water is added to the grid cell's antecedent root-zone water-content term used in the following day's water-balance calculation. The surface-water flow depth routed across the grid cell defining the outflow location of the watershed is converted to a daily mean discharge flow rate, in cubic feet per second (cfs),[9] which can be compared to measured stream flow for model calibration.

Time-averaged net-infiltration rates are calculated by accumulating the simulated daily net-infiltration amounts obtained at the end of the daily water-balance loop. Time average rates also are calculated for the remaining components of the water balance (precipitation, snowmelt, sublimation, evapotranspiration, infiltrated run-on, root-zone water-content change, and runoff) for all model grid cells and are included in the main output file used for developing the net-infiltration results. The time-averaged rates for all components of the water balance simulated at each grid cell are averaged over the watershed model domain and compared against the time-averaged watershed outflow to check the consistency of the simulated water balance for the entire watershed.

Output from INFIL V2.0 also includes spatially averaged daily water-balance terms for all components of the water balance. The daily output indicates the average inflow, outflow, and change in storage rates over the area of the watershed being simulated. The spatially averaged daily water balance is compared against the simulated daily outflow to provide a water-balance check for each day simulated. The simulated daily water balance rates are averaged over time and compared against the spatially averaged water-balance rates simulated at each grid cell as an additional method of checking the consistency of the simulated water balance for the entire watershed.

6.2 DAILY WATER AND ENERGY BALANCE

[9] Cubic feet per second is a standard unit used for volume discharge rates in surface water hydrology

The estimation of spatially distributed net-infiltration rates consists of a daily simulation of net infiltration in response to a daily water- and energy-balance calculation performed separately for all model elements within a watershed bounded by surface-water flow divides. The daily water-balance calculation used in INFIL V2.0 is:

$$R_{off} = P - SF + IR_{on} + SM - SB - SW - ET - I \quad \text{(Eq. 6-1)}$$

where I = net infiltration, P = precipitation (rain and snow), SF = snowfall, SB = sublimation, SM = snowmelt, SW = change in water-content storage within the root zone, ET = evapotranspiration, IR_{on} = infiltrated surface-water run-on, and R_{off} = surface-water runoff generated by excess precipitation, snowmelt, or run-on. It is important to note that runoff, not net infiltration, is calculated as the solution to the water-balance equation. A unit gradient is assumed and net infiltration is incorporated in the water-balance formulation as a temporary potential net-infiltration term and is limited by the field-scale-saturated hydraulic conductivity of the soil or bedrock underlying the root zone.

The daily water-balance calculation performed for a root zone is illustrated in Figure 5-1, which was discussed in Section 5. In this figure water balance of the root zone is schematically represented for a single soil layer. In modeling the daily water-balance, parameters affecting the daily water balance, such as soil thickness, soil and bedrock properties, and various surface and vegetation characteristics, are uniquely defined for each grid cell. The difference between field capacity and residual water content is commonly referred to as available water capacity in soil science terms and that is the water available for plants. Therefore this is the zone in which the transpiration part of evapotranspiration processes take place. The infiltration rate of precipitation, snowmelt, or surface-water run-on into the root zone from the land surface is limited by the saturated hydraulic conductivity of the grid cell soil type (or the bulk saturated hydraulic conductivity of the grid cell bedrock type in cases of no soil cover). Precipitation and surface-water flow rates are defined using an estimated 2-hour storm duration for summer storm events and an estimated 12-hour storm duration for winter storm events. If the precipitation or snowmelt rate exceeds the saturated hydraulic conductivity of the top root-zone layer, the excess precipitation or snowmelt is added to the runoff term for that grid cell. During the simulation of surface-water flow, the infiltration of surface-water run-on is also limited by the saturated hydraulic conductivity of the top root-zone layer. Surface-water run-on exceeding the saturated hydraulic conductivity of the top root-zone layer is added to the runoff term routed to the downstream grid cell.

As noted in Figure 5-1, infiltration is represented as equal to recharge. This is not entirely the case because in a deep unsaturated zone there are several mechanisms that may remove a small amount of water and the timing of recharge is not accounted for. At Yucca Mountain there are unsaturated zone groundwater ages of over 7,000 years.

6.3 DAILY CLIMATE INPUT

Infiltration occurs in response to daily precipitation that occurs in particular temporal and spatial patterns. Stochastic representations of infiltration would be required to predict infiltration for long time periods without daily input; however, no infiltration data are available for the development of long-term patterns. Therefore, using stochastic representations of precipitation and daily input to simulate infiltration is appropriate.

The daily climate input file is the primary control for the timing and duration of the simulation. The daily climate input file defines the time domain through which the simulation occurs by providing a real-time sequential input of daily climate parameters. The file is ASCII column formatted and at minimum consists of the year number, the day of year number, and the total daily precipitation amount but can also consist of maximum, minimum, and average daily air temperature, along with total daily snowfall accumulation.

The primary input provided by the daily climate-input file is total daily precipitation, in millimeters, and this drives the daily water-balance calculation. Average daily air temperature, in degrees Celsius, is not required as input, but if not provided in the daily climate input file, this parameter is modeled internally by INFIL V2.0 using Equation 20 from Flint et al. (1996):

$$T = T1 - T2 \{\mathrm{Sin}[(D/366)*2*\pi + 1.3]\} \qquad \text{(Eq. 6-2)}$$

where T = modeled daily air temperature, D = day of year number, T1 = mean annual air temperature, and T2 = mean seasonal variation of average daily air temperatures above the mean during summer and below the mean during winter (the ½ amplitude of the sine wave). T1 and T2 were calculated as 17.3 and 11.74 degrees Celsius, respectively, using measured air temperature data from Yucca Mountain (DTN: GS000208312111.002).

The daily climate input file provides point values of total daily precipitation and average daily air temperature for a given day of the simulation. These values are representative of the conditions at locations having elevations of approximately 1,400 meters, which represents the approximate average elevation of the land surface above the potential repository. Precipitation and air temperature are distributed spatially across all model grid cells using empirical elevation models. The precipitation/elevation correlation, caused by the adiabatic cooling of air masses interacting with mountainous terrain, has been studied in the southern Nevada region and correlation models between elevation and annual as well as seasonal precipitation amounts have been defined (French, 1983; Hevesi et al., 1992; Hevesi and Flint, 1998). The precipitation/elevation correlation model used in INFIL V2.0 for modern climate was from Hevesi and Flint (1998, Table 4, DTN: GS960108312111.001) for the sample of 114 precipitation stations with a minimum of 8 years of record, where the coefficients in the table are based on mean annual precipitation transformed as ln(MAP) x 1,000. The model estimated mean annual precipitation distributions using the relation:

$$P_d^k = P_d * \exp(0.0006458*E + 4.317)/MAP \qquad \text{(Eq. 6-3)}$$

where P_d^k = the elevation-corrected daily precipitation estimate (in millimeters) for day d at model element k, P_d = the point precipitation estimated for day d provided by the daily climate input file, E = elevation (in meters), and MAP = mean annual precipitation (in millimeters). For the monsoon and glacial transition climate scenarios, the slope defined by Equation 6-3 was adjusted to account for assumed changes in the precipitation/elevation correlation based on estimates of precipitation-elevation correlations presented by Thompson et al. (1999), indicating a reduction in orographic effects on precipitation for wetter paleoclimates.

Atmospheric pressure decreases with increasing altitude. Consequently, stirring of an atmospheric layer causes rising parcels of air to cool by adiabatic expansion, and sinking parcels to correspondingly warm by compression. The net effect of this is a vertical decrease in temperature with increase in elevation called the adiabatic lapse rate. The adiabatic lapse rate, or air temperature/elevation correlation is cited in numerous references as about 9.8 degrees C per kilometer and was cited for this work using Maidment (1993, p. 2.27):

$$T_d^k = 0.0098 * (1400.-E^k) + T_d \qquad \text{(Eq. 6-4)}$$

where T_d^k is the elevation-adjusted air temperature for grid cell k based on elevation E and daily air temperature T_d (either provided in the daily climate-input file or simulated using Equation 6-2). The elevation E is subtracted from the estimated mean elevation for the potential repository area that is indicated in the equation as 1,400 m. This is the approximate average ground surface elevation of the potential repository.

Cloud cover is a variable affecting the energy-balance calculation and is indirectly accounted for in the model as an empirical function of daily precipitation magnitude. For days with precipitation, the modeled clear-sky potential evapotranspiration rate is reduced according to:

$$APET_d = PET_d/[(4*P_d/25.4) + 1] \qquad \text{(Eq. 6-5)}$$

where APET = adjusted potential evapotranspiration for day d (in millimeters), PET_d = the Priestley-Taylor modeled clear-sky potential evapotranspiration for day d (PET is discussed further in Section 6.4.4), and P_d = modeled daily precipitation for day d. The coefficient 25.4 converts inches to millimeters, and the value 4 is an estimate that reduces the PET by approximately 25 percent due to cloud cover that exists whenever it rains. The assumption is that the energy for ET is reduced in the presence of clouds (associated with precipitation) and the more rain there is, the less ET there is. The model is fairly insensitive to this value.

6.4 SNOW PACK SUB-MODEL

Precipitation is simulated as snowfall for a grid cell location if the average air temperature is less than or equal to 0 degrees Celsius. When snowfall occurs, all precipitation for that day is assumed to occur as snow at that location. However, because air temperature is distributed spatially using the elevation correlation model, snowfall and snow pack accumulation may occur at higher elevation cells while rain occurs at lower elevations within the same watershed.

Snowfall is accumulated into a snow pack storage term and is removed from the root-zone water balance. If snow pack exists and the air temperature is less than 0 degrees Celsius, water is removed from the snow pack by using an empirical sublimation-saltation-suspension model under the assumption that in upland areas advective wind-transport processes tend to cause snow removal rather than deposition over most areas. The three processes are grouped into a single empirical "sublimation" model that also includes evaporation of snowmelt and sublimation (but not saltation and suspension) when the air temperature exceeds 0 degrees Celsius:

$$SB^k = A1 * APET^k,\ T^k <= 0 \quad \text{(sublimation/advective losses)} \qquad \text{(Eq. 6-6)}$$
$$SB^k = A2 * APET^k,\ T^k > 0 \quad \text{(evaporation of snowmelt and sublimation)}$$

where SB^k = total snow pack losses to the atmosphere (in millimeters), $APET^k$ is the cloud cover adjusted Priestley-Taylor potential evapotranspiration rate[10], (in millimeters/day), and T^k is the average air temperature simulated for grid cell k (in degrees Celsius). The model coefficients were estimated based on limited information indicating the average percentage of snow pack losses due to sublimation and advective energy processes (Maidment, 1993, pp. 7.4-7.10). For all simulations using the snow pack sub-model, A1 was set to 0.1 and A2 was set to 0.3 in the model control file. This is an assumed relation to account for an increase in snow pack losses to the atmosphere when the average daily air temperature is above freezing. If a snow pack exists and air temperature is greater than 0 degrees Celsius, a combined sublimation of snow and evaporation of snowmelt is simulated, and the APET term is reduced by the sublimation/evaporation rate SB to provide a potential transpiration rate for the root zone. Thus, the model allows reduced transpiration to occur when a snow pack exists but only if air temperature is higher than 0 degrees. For all days when air temperature is 0 degrees or less, transpiration is set to zero, and only sublimation can occur, provided a snow pack exists.

If air temperature is greater than 0 degrees Celsius, snowmelt is simulated as an empirical linear function of average daily air temperature (Maidment, 1993, pp. 7.4-7.10) using a standard temperature index modeling approach:

$$SM^k = A * T^k \qquad \text{(Eq. 6-7)}$$

where SM is the modeled snowmelt (in millimeters) for grid cell k; T is the modeled average daily air temperature (degrees Celsius) for grid cell k; and A was set to 1.78, which is the coefficient used for modeling snowmelt in the Sierra Nevada during April (Maidment, 1993, Table 7.3.7, p. 7.24) The simulated snowmelt is carried back into the root-zone water-balance calculation as an influx term.

6.5 POTENTIAL EVAPOTRANSPIRATION AND THE NET RADIATION SUB-MODEL

Total daily potential evapotranspiration is modeled for each grid cell using the Priestley-Taylor equation (Priestley and Taylor, 1972):

$$PET_d^{\,k} = \alpha * [s/(s+\gamma)_d^{\,k} * (RN_d^{\,k} - GH_d^{\,k}) / 2.45*10^6] \qquad \text{(Eq. 6-8)}$$

where $PET_d^{\,k}$ is potential evapotranspiration (in millimeters) on day d for grid cell k; S is the slope of the saturation vapor pressure-temperature curve; γ is the psychometric constant; RN is modeled net radiation; and GH is estimated ground-heat flux, which is modeled using Equation 22 from Flint et al. (1996):

$$GH = -20 + 0.386(RN) \qquad \text{(Eq. 6-9)}$$

and $2.45*10^6$ converts the energy units to millimeters of water. In Equation 6-8, α is used as an empirical scaling factor to account for the missing advective energy term in the Priestley-Taylor

[10] The potential evapotranspiration rate used in the sublimation model uses a Priestley-Taylor α coefficient value of 1.26 to account empirically for the advective component of the total energy balance and is not necessarily equivalent to the values of the coefficient used in the root-zone model.

equation. For wet conditions having freely evaporating surfaces, α is often set to 1.26 (Priestley and Taylor, 1972; Flint and Childs, 1991; DTN: GS000300001221.009). For dry conditions, available moisture becomes the limiting factor controlling actual evapotranspiration, and α can be modeled as an empirical scaling function, α′, using a relative saturation term (Flint and Childs, 1991). In the root-zone water-balance sub-model, α′ is defined as an empirical function of relative saturation within the root zone by using a method described in Section 6.4.6.

The s/(s+γ) term is modeled as a function of average daily air temperature by using Equation 19 from Flint and et al. (1996):

$$s/(s+\gamma)_d^k = -13.281 + 0.083864 * TA_d^k - 0.00012375 * (TA_d^k)^2 \qquad \text{(Eq. 6-10)}$$

where TA^k is the average daily air temperature on day d for grid cell k, in Kelvins. Equation 6-10 was defined using parameter values obtained from performing a regression on data from Campbell (1977, Table A.3), and provides an indication of the relative effect of air temperature on potential evapotranspiration, which varies for different temperature ranges. In Figure 6-3, Equation 6-10 is compared with selected values taken from (Campbell, 1977, Table A.3) to illustrate the greater relative change in the s/(s+γ) term for the lower air temperatures in the range –5 to 5 degrees Celsius as compared to temperatures in the range of 25 to 35 degrees Celsius. For example, a decrease in air temperature from 5 to 0 degrees Celsius results in a 17 percent reduction in s/(s+γ) and thus potential evapotranspiration, while a decrease in air temperature from 35 to 30 degrees Celsius causes only a 5 percent reduction in the s/(s+γ) term.

Figure 6-3. Relative effect of air temperature change on the modeled s/(s+γ) term of the Priestley-Taylor equation used for estimating potential evapotranspiration (Appendix 3).

Total daily net radiation is the primary component of the energy balance determining potential evapotranspiration and is modeled using Equation 21 from Flint et al. (1996):

$$RN_d^k = -71 + 0.72 * K_d^k\downarrow \qquad \text{(Eq. 6-11)}$$

where RN is total net radiation, in w/m^2, on day d for model element k, and K↓ is simulated incoming solar radiation which is modeled using a version of the SOLRAD program developed by Flint and Childs (1987). To account for seasonal changes in the solar trajectory as well as terrain effects across model elements, SOLRAD calculates solar position on an hourly[11] basis from sunrise to sunset as a function of the day of year and geographic position of each grid cell (Flint and Childs, 1987). Terrain effects (blocking ridges) on incoming solar radiation are modeled using topographic parameters calculated from the DEM and included as input in the geospatial parameter file. Topographic parameters include grid cell slope, aspect, and 36 blocking ridge angles that define shading effects and reductions in skyview for every 10 degrees in the horizontal plane, starting with the UTM northing axis as the 0-degree azimuth. Shading causes a reduction in direct beam radiation, and diminished skyview decreases diffuse radiation. These effects can become important in rugged mountainous terrain.

[11] The time step is a user-specified option included in the model control file. Although a 1-hour time step is allowed, a 2-hour time step was used to reduce simulation run time.

6.6 ROOT-ZONE SUB-MODEL: INFILTRATION, PERCOLATION, AND REDISTRIBUTION

Water infiltrating and percolating through the multi-layered root-zone system is modeled as a cascading piston-flow process. Downward percolation is modeled as a "forward" cascade initiated by adding the total volume of water infiltrating the top layer of the root zone to the antecedent water content of the layer. The new water content is calculated using the layer thickness and compared against the field capacity defined by the grid cell soil type. The volume of water exceeding the field capacity becomes downward percolation that is added to the antecedent water content of the underlying layer, and the new water content of the underlying layer is compared against the field capacity of that layer. If the potential percolation volume exceeds the saturated soil hydraulic conductivity or the saturated bulk bedrock hydraulic conductivity of the underlying layer, the downward percolation rate is set equal to the saturated hydraulic conductivity of the underlying layer, and the excess water volume is added to a temporary storage term for the overlying layer. The process is repeated for each soil and bedrock layer in the root zone (in the case of the model used in this analysis/modeling activity, a maximum of three soil layers and one bedrock layer was used) until the bottom layer is reached, which completes the forward cascade.

The volume of water that has percolated into the bottom bedrock layer (which may be zero if the field capacity of an overlying layer was not exceeded) is compared against the effective root-zone storage capacity of the bedrock. If a bedrock layer exists in the root zone, the effective root-zone storage capacity of the bedrock layer is calculated based on the estimated root-zone depth, the estimated soil depth, and the estimated effective fracture porosity of the rock. The volume of water exceeding the bedrock storage capacity is the potential net-infiltration volume. For thick soils, there is no bedrock layer in the root zone. The thickness of the bedrock root-zone layer is set to zero, the effective fracture porosity for the bottom bedrock layer becomes zero, and all water exceeding the field capacity of the bottom soil layer (the third soil layer) is potential net infiltration unless limited by the saturated bulk hydraulic conductivity of the underlying soil or bedrock. For locations where the soil depth is estimated to be 6 meters or greater, the underlying bedrock properties are defined using alluvium/colluvium properties. Based on analysis of neutron moisture meter data (Flint and Flint, 1995), the maximum depth of infiltration in non-channel alluvial locations is 6 meters, therefore there is no need to provide bedrock properties in these locations. The actual net-infiltration volume is calculated after evapotranspiration is simulated throughout the root zone and is limited by the bulk saturated hydraulic conductivity of the underlying rock type. The potential net-infiltration volume exceeding the bulk saturated hydraulic conductivity is added to the temporary storage term of the bottom root-zone layer.

Starting with the bottom root-zone layer, a reverse cascade is performed to determine if runoff is generated. The volume of water in the temporary storage term is compared against the total storage capacity of each layer defined by the porosity (or effective fracture porosity in the case of bedrock) and layer thickness. If the volume of water in the temporary storage term exceeds the storage capacity, the excess water is added to the temporary storage term of the overlying layer. The process is repeated until the top layer is reached, completing the reverse cascade. The volume of water in the temporary storage term exceeding the storage capacity of the top layer is added to the potential runoff volume calculated for that grid cell. The final runoff volume is calculated following the simulation of evapotranspiration from the root zone.

6.7 ROOT-ZONE SUB-MODEL: EVAPOTRANSPIRATION, RUNOFF, AND NET INFILTRATION

After the completion of the reverse cascade and the placement of excess water into temporary storage terms, evapotranspiration is simulated for each root-zone layer using a dynamic root-zone weighting function and the modified Priestley-Taylor. Evapotranspiration is simulated only for days with air temperature greater than 0 degrees Celsius. The dynamic weighting is based on calculated relative saturations for each root-zone layer and the relative distribution of water (based on saturation) throughout all layers. The purpose of the dynamic weighting is to increase root activity for the wettest layer. Static root density weights are also incorporated into the dynamic weighting function, setting an upper limit on root activity within each layer. For the top soil layer, the bare-soil evaporation term is added to the transpiration term. Using the calculated weighting terms, evapotranspiration is simulated by applying a form of the modified Priestley-Taylor equation developed by Flint and Childs (1991, coefficients in DTN: GS000300001221.009) to each layer of the root zone:

$$ET^k = \alpha' * PET^k \qquad \text{(Eq. 6-12)}$$
$$\alpha' = \Sigma_i\{wgt_i * [a^k (1-\exp(b^k * relsat_i^k))]\}$$

where ET^k is total root-zone evapotranspiration for grid cell k; PET^k is the adjusted clear-sky simulated equilibrium[12] potential evapotranspiration rate for grid cell k; $relsat_i^k$ is the relative saturation calculated for layer i within grid cell k; a^k and b^k are the Priestley-Taylor model coefficients for grid cell k supplied as soil- and rock-type input parameters in the model control file (in this analysis, the coefficients were identical for all soil and rock types but were varied between different climate scenarios and between soils and rocks). After water contents for each layer are reduced according to the calculated evapotranspiration rates, the final runoff and net-infiltration terms are calculated, and the new water-content terms for each root-zone layer are up-dated for the following day's water-balance calculation.

6.8 SURFACE-WATER FLOW-ROUTING SUB-MODEL

At the completion of the root-zone water balance loop, the surface-water flow sub-model is called if the runoff accumulation term is greater than zero (at least one grid cell has generated runoff). The sub-model uses an instantaneous flow routing (IFR) method to perform an efficient time-independent simulation of surface-water flow. The purpose of the routing algorithm is to calculate the lateral redistribution of water throughout the watershed domain and to allow for the infiltration of surface water as it is routed. The surface water flow routing algorithm is fully coupled with the algorithm used to calculate infiltration into the root zone. There is no need to predict a flood wave, peak flows, or backwater effects, and thus a finite difference approximation of the St. Venant equations is not required. The IFR method assumes that the duration of surface-water flow at Yucca Mountain is less than 24 hours, which is generally supported by the available stream flow records and field observations (Savard, 1995; Flint et al., 1996, Figure 23; DTN: GS960908312121.001). For the purpose of calculating daily net infiltration, it is not necessary to perform surface water flow routing at time steps less then the daily water balance, especially when stream flow events are known to be episodic and have duration less then 24 hours (at least for current climate conditions).

[12] The equilibrium potential evapotranspiration rate is calculated using $\alpha = 1.0$, and is used to represent the non-advective component of the energy balance.

The routing is performed using parameters calculated by the routine CHNNET16 V1.0 and included in the geospatial parameter input file. The routing parameters identify downstream cell connections for all cells in the model domain. The flow routing routine determines which of eight surrounding grid cells is the lowest in elevation and calculates the flow directions for each grid cell by first sorting the entire base-grid based on elevation, then using a standard D8 convergent flow routing algorithm in the routine. Multiple cells are allowed to route to a single cell, but any given cell can route to only one downstream grid cell (as opposed to two in cases of flow dispersion). In this way, channels are defined for every watershed. In general it is adequate to drive all flow along one connected node pair. The flow routing algorithm models convergent flow only. Inaccuracies resulting from a lack of flow dispersion are not significant within the area of the potential repository, and are not significant within most areas of the UZ flow and transport model. Inaccuracies resulting from a lack of flow dispersion tend to increase as flow is routed across more gently sloping alluvial fans, particularly in cases where the stream channel becomes braided or is not well defined.

The IFR sub-model repeats the infiltration and percolation simulation performed in the water- balance loop, providing a 2-dimensional coupling of surface-water flow and infiltration. As with precipitation and snowmelt, infiltration of run-on is a function of the storage capacity and hydraulic conductivity of the underlying soils and bedrock. The fraction of the total grid cell area affected by surface-water flow is defined in the model control file and is used to scale the bulk hydraulic conductivity of the grid cell as a means of limiting total infiltration volumes along the width of the active channel. The scaling is performed by using an estimate of the average fraction of the total grid cell area wetting by surface water flow. For example, if the scaling factor is 0.1, only 10 percent of the 30m x 30m area of the grid cell is wetted, on average, by surface water. Thus the effective saturated hydraulic conductivity used to limit the volume of water infiltrating into the grid cell is multiplied by 0.1 to account for the reduction in area. Saturated conditions along the active channel are assumed for estimated storm duration of 2 hours for summer storms and 12 hours for winter storms. Positive pressure heads are assumed to be negligible and are not included in the calculation of infiltration volumes. The increase in water content for each layer in the root zone is stored and included in the following day's root-zone water-balance calculation.

Surface water that is routed off the model grid is stored as an outflow term. For watershed model domains, there is only one outflow point and the outflow term represents stream discharge from the watershed. The outflow term is incorporated into a global mass-balance calculation using:

$$D = \sum R_{off}{}^{k} - \sum IR_{on}{}^{k} = \sum P^{k} + \sum SM^{k} - \sum SB^{k} - \sum SW^{k} - \sum ET^{k} - \sum I^{k} \qquad \text{(Eq. 6-13)}$$

where D is the watershed outflow, P is defined for this equation as rainfall, and the water balance terms defined in Equation 6-1 are summed for all grid cells k in the watershed. Equation 6-13 is calculated for each day of the simulation as a means of verifying the mass balance over the modeling domain.

7. MODEL INPUT

User-defined model inputs for INFIL V2.0 consist of four general groups: (1) geospatial parameters, (2) hydrologic properties, (3) empirical model coefficients, and (4) daily climate input. Additional model coefficients are defined within the model source code The data acquired or developed and used as input for modeling net infiltration consist of either ASCII digital data or proprietary formats for acquired software applications (ARCINFO map coverages, EARTHINFO data formats).

7.1 STANDARD INPUT

7.1.1 Accuracy of Input Parameters

The accuracy of all model inputs could not be fully quantified at the time of this activity. Uncertainty in model inputs was not incorporated into the results developed in this report. A preliminary uncertainty analysis is provided by CRWMS M&O (2000b), and will be used in the UZ Flow and Transport Process Model Report (CRWMS M&O 2000a) to provide a limited evaluation of model accuracy and uncertainty based on estimated bounds and distributions for a few selected input parameters. The development of input distributions for the selected parameters is discussed in Section 4.

7.1.2 Data Requirements

Input and Output Data Defaults

There are no data defaults. Because the program is free format, the user must enter a place-holder value for all read statement parameters. It is the user's responsibility to recognize realistic and correct data.

File Formats

Most data variables are entered in free format (list directed input/output). The variable order is included in Appendices 1, 2, and 3.

Allowable/Tolerable Ranges for Inputs and Outputs

There are no data defaults. Because the program is free format, the user must enter a place-holder value for all read statement parameters. It is the user's responsibility to recognize realistic and correct data.

All model input required directly for simulating net infiltration using the developed model code INFIL V2.0 is provided by three separate ASCII files. These are the model control file, geospatial parameter input file, and the daily climate input file. The model control file specifies input and output options, input and output file names, modeling options, simulation period, model coefficients, and hydrologic properties. The Geospatial Parameter Input File is used for modeling grid geometry and watershed modeling domains.

Table A1-1 indicates the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for tests. Any special conditions or modifications made to the input files used for a test case will be identified.

7.2 MODEL CONTROL INPUT FILE

The model control file specifies input and output options, input and output file names, modeling options, simulation period, model coefficients, and hydrologic properties. See Appendix 1 for detailed description and example file.

7.3 DAILY CLIMATE INPUT FILE.

As discussed in Section 6.3, the daily climate input file is the primary control for the timing and duration of the simulation. The daily climate input file defines the time domain through which the simulation occurs by providing a real-time sequential input of daily climate parameters. The file is ASCII column formatted and at minimum consists of the year number, the day of year number, and the total daily precipitation amount but can also consist of maximum, minimum, and average daily air temperature, along with total daily snowfall accumulation.

The reader is referred to Appendix 1-B for a detailed description and example of the Daily Climate Input File.

7.4 GEOSPATIAL PARAMETER INPUT

The net infiltration modeling procedure begins with building a geospatial input parameter base grid using the selected digital elevation model (DEM) to define the base-grid geometry. The parameters included in the geospatial-parameter input file defining each watershed model domain are: grid cell identifier, UTM easting (meters), UTM northing (meters), latitude (decimal degrees), longitude (decimal degrees), row identifier, column identifier, downstream grid cell identifier, number of upstream cells, elevation (meters), slope (degrees inclination from horizontal), aspect (degrees from north), and other physical attributes, including soil-type identifier, soil depth class identifier, soil depth (meters), rock-type identifier, topographic position identifier, vegetation-type identifier, percent vegetation cover, and 36 blocking-ridge angles.

7.4.1 Topographic Parameters (Slope, Aspect, and Blocking Ridges)

Topographic parameters, such as the flow-routing parameters, are calculated directly from the DEM and included in the geospatial-parameter input file. Additional topographic parameters include slope, aspect, and blocking ridge angles, which are required by the SOLRAD routine in the potential evapotranspiration sub-model. The 36 blocking ridge angles (degrees of inclination above horizontal) are calculated at each 10-degree horizontal arc (with the azimuth aligned in the UTM northing direction) for each grid cell using the routine BLOCKR7 V1.0. Calculations were performed using the DEM as input and a technique for approximating the 10-degree horizontal angles based on northing and easting grid cell distances. The blocking ridge parameters cannot account for topographic influences outside of the DEM, and thus the blocking ridge effect is only partly accounted for along the perimeter of the DEM. Slope is also a required input parameter for estimating soil depths using the routine SOILMAP6 V1.0. Slope and aspect were calculated for the 1996 version of the net-infiltration model (Flint et al., 1996) using standard GIS applications in ARCINFO V6.1.2.

7.4.2 Soil and Bedrock Classification

Soil-Depth Classes

A soil-depth-class map consisting of four separate soil-depth classes was developed for the 1996 net-infiltration model (Flint et al., 1996, Figure 13; DTN: GS960508312212.007). The four depth classes represent different ranges in actual soil depths that were estimated using a combination of Quaternary geologic maps, field observations, and soil depth recorded at borehole sites (Flint and Flint, 1995, Table 2). Depth class #1 identifies locations with soil depths ranging from 0 to 0.5 meter and primarily occurs in rugged upland areas. Depth class #2 identifies deeper soils ranging from 0.5 to 3.0 meters occurring at mid to lower side-slope locations in upland areas affected by slumps, slides, and other mass-wasting processes. Depth class #3 identifies locations in the transition zone between upland areas and alluvial fans or basins with intermediate soil depths ranging from 3 to 6 meters. Depth class #4 identifies soils with depths of 6 meters or greater. The soil-depth classes were used to estimate soil depths based on calculated slope and an empirical soil-depth model described Appendix 1-C.

Soil Types

A soil-type classification map is defined in Flint et al. (1996; Figure 14, DTN: GS960508312212.007). The soil-type classification is based on a recombination of mapped Quaternary surficial deposits and defines 10 unique soil types based primarily on differences in soil texture. Soil texture and porosity data were obtained using field samples and laboratory measurements (DTN: GS950708312211.002) as described in Flint et al. (1996; p. 42). Soil hydrologic properties consisting of hydraulic conductivity, residual water content, and field capacity were both measured and estimated using the soil texture data as described in Flint et al. (1996, p. 41) and Appendix 1-C. The soil hydrologic properties included directly as model input (using the model control file) for INFIL V2.0 consist of porosity, field capacity, residual water content, and saturated hydraulic conductivity, and are the same as the properties used in the 1996 version of the net-infiltration model (INFIL V1.0) which are listed in Flint et al. (1996, Table 4, p. 42).

7.4.3 Bedrock Geology

Bedrock geology was defined for each grid element using three different ARCINFO map coverages and a vector to raster conversion performed by ARCINFO. Figure 7-1 indicates the areal coverage of the three maps: the 1:6,000-scale Bedrock Geologic Map of the central block area by Day et al. (1998, DTN: GS971208314221.003), the Preliminary Geologic Map of Yucca Mountain by Scott and Bonk (1984, DTN: MO0003COV00095.000), and the Geologic Map of the Topopah Spring Northwest Quadrangle by Sawyer et al. (1995, DTN: GS000300001221.010). Within the UZ flow and transport model area, bedrock geology for the net-infiltration model (which is defined as a unique integer identifier for each rock type in the geospatial-parameter input file) is primarily defined by Day et al. (1998). Bedrock geology for the northern and southern perimeter sections of the UZ flow and transport model area is defined by Scott and Bonk (1984).

Figure 7-1. Overlay of the three geologic maps used to define rock types underlying the root zone and included in the bottom root-zone layer. (Appendix 3)

Bedrock geology for the 1996 version of the net-infiltration model was defined by the Scott and Bonk (1984; DTN: MO0003COV00095.000) and the Sawyer et al. (1995, DTN: GS000300001221.010) map coverages (Flint et al., 1996, Figure 10). To incorporate the Day et al. (1998) geology for INFIL V2.0, the rasterized version of the Day et al. (1998) map coverage (DTN: GS971208314221.003) was integrated with the bedrock geology defined by the 1996 version of the geospatial input file (DTN: GS000308311221.004) using the routine GEOMAP7 V1.0. For some locations within the Day et al. (1998) geologic map coverage, bedrock geology for the net-infiltration model is defined by GEOMAP7 V1.0 using the Scott and Bonk (1984) geologic map (DTN: MO0003COV00095.000). The purpose of including the Scott and Bonk (1984) geology (DTN: MO0003COV00095.000) within the Day et al. (1998) map coverage (DTN: GS971208314221.003) is to estimate bedrock geology for some locations mapped by Day et al. (1998) as alluvium or colluvium and having intermediate soil depths less than 6 meters (as defined by the soil depth class map from Flint et al. (1996, Figure 13; DTN: GS960508312212.007). Locations having intermediate soil depths primarily occur in the transition from upland areas to alluvial fans and basins. Assigning a bedrock type of colluvium or alluvium to grid cells having a soil depth less than 6 meters was considered problematic in terms of modeling net infiltration.

Conceptually, all grid cells with a soil depth less than 6 meters should be underlain by a consolidated bedrock type to avoid inconsistency in terms of the assigned soil depth and the estimated root-zone depth. The available geologic maps, however, are representations of the surface geology and do not necessarily indicate bedrock geology for locations having one to 6 meters of soil cover. In general, the consolidated bedrock geology defined by Scott and Bonk (1984) extends farther into the intermediate soil-depth areas then the consolidated bedrock geology defined by Day et al. (1998) and thus was substituted by GEOMAP7 V1.0 for the colluvium or alluvium defined by Day et al. (1998) at many locations with intermediate soil depths.

To ensure that a consolidated rock type was defined as the bedrock geology for all grid cells having less than 6 meters of soil, the routine GEOMOD4 V1.0 was applied to the geospatial parameter file created by GEOMAP7 V1.0. GEOMOD4 V1.0 also performs a modification of the depth-class #3 boundary defined in Flint et al. (1996, p. 40) for all cases where the boundary was found to be inconsistent with the updated bedrock geology. The algorithm creates a new buffer zone of intermediate soil depths defined by depth class #3 using the updated alluvium/colluvium – consolidated bedrock boundary. The result is that the modified depth-class parameters defined by GEOMOD4 V1.0 do not allow for grid cells with depth class #4 (thick soils) to be adjacent to grid cells with thin soils (depth classes #1 and #2). All thin soils are separated from the thick soils by at least one grid cell assigned to depth class #3. Once the soil-depth classes are finalized, GEOMOD4 V1.0 identifies all grid cells having less than 6 meters of soil and alluvium or colluvium as bedrock and interpolates the bedrock geology based on the most prevalent consolidated rock type found within a search neighborhood of one to two grid cell layers.

Bedrock geology is represented in the geospatial-parameter-input file using a unique integer identifier for each rock type (see Appendix 1-C for details). The identifier is linked to an estimated bulk (field-scale) saturated hydraulic conductivity in the model control file. The bulk saturated hydraulic conductivity represents a combination of the saturated hydraulic conductivity of the matrix (Flint, 1998, DTN: GS000308312231.002) and the saturated hydraulic conductivity of fracture-fill material (DTN: GS950708312211.003) based on the fracture density of the particular rock type. The saturated hydraulic conductivity of the fracture fill material was measured in the laboratory and averaged 43.2 mm/d (DTN: GS950708312211.003) (see Appendix 1-C). Estimates of saturated hydraulic conductivity were calculated using these values of fracture conductivity for the percentage of area covered by the fracture per square meter of rock, given the fracture density and size of aperture available through which water can flow. This was added to the saturated hydraulic conductivity of the rock matrix and weighted averages of bulk bedrock saturated hydraulic conductivity were calculated on the basis of percentages of matrix and fractures by lithostratigraphic unit. These calculations are also provided in Flint et al. (1996, Table 2), in DTN: GS000308311221.004, and in Appendix 1-C. Bulk saturated hydraulic conductivity values for the updated Day et al. (1998) geology rock types were defined using lithologic correlations with the Scott and Bonk (1984) geology (DTN: MO0003COV00095.000). In general, the number of unique bedrock units with different bulk hydraulic conductivity values decreased with the incorporation of the Day et al.(1998) geology. The bulk saturated hydraulic conductivities range from a minimum of less than 10 mm/year for densely welded tuffs with low matrix hydraulic conductivity and relatively small fracture densities to a maximum of more than 100,000 mm/year for alluvium and colluvium.

7.4.4 Estimated Root-Zone Depth

Estimated Soil Depth

Soil depth is estimated using a combination of the soil-depth class map and an estimated linear relation between soil depth and slope within each depth class. The empirical soil-depth model is based on an assumed soil depth/slope correlation (DTN: GS000308311221.004), Appendix 1-C, within the soil depth classes defined for the 1996 version of the net-infiltration model (Flint et al., 1996; DTN: GS960508312212.007). The conceptual soil-depth model for depth class #1 assumes that soils are thinnest at summit and ridge-crest areas as well as steep side slopes. Thicker soils are expected to occur at the relatively gently sloping shoulder areas that define the transition between summit or ridge-crest areas and steep sideslope areas. Thicker soils are also expected to occur for more gently sloping foot-slope locations. The model for soil-depth class 1 is defined by:

$$D = 0.03 * S + 0.1, S \leq 10 \qquad \text{(Eq. 6-14)}$$
$$D = 0.013 * (10 - S) + 0.4, 10 < S < 40$$
$$D = 0.01, S \geq 40$$

where D = soil depth (in meters), and S = slope (degrees). The model for depth class #2 is defined by:

$$D = 2 - (0.05 * S), \quad S < 32 \qquad \text{(Eq. 6-15)}$$
$$D = 0.4, \quad S \geq 32$$

and the model for depth class #3 is defined by:

$$D = 6 - (0.16 * S), \quad S \leq 25 \qquad \text{(Eq. 6-16)}$$
$$D = 2.0$$

For depth class #4, soil depth is set to a uniform depth of 6 meters.

Figure 7-2 shows the spatial distribution of estimated soil depth (DTN: GS000308311221.004) with relatively thin soils less than 0.2 meter deep along steep sideslopes, and thicker upland soils 0.3 to 0.4 meter along ridge-top and shoulder areas. All locations having a soil depth of 6 meters are underlain by alluvium or colluvium rock-types. The six-meter soil depth represents only the depth of the root zone, not the actual soil depth.

Figure 7-2. Estimated soil depth using the 1996 soil-depth class map and calculated land-surface slope (Appendix 3).

Estimated Root-Zone Depth

The estimated soil-depth map is used to estimate the depth of the root zone by using an empirical model based on field observations and neutron moisture meter data analyses:

$$RZ^k = SD^k + [RZc - (SD^k/RZd)], \quad [RZc - (SD^k/RZd)] \geq 0 \qquad \text{(Eq. 6-17)}$$
$$RZ^k = SD^k, \quad [RZc - (SD^k/RZd)] \leq 0$$

where RZ is the estimated root-zone depth (in meters) at grid location k; SD is the estimated soil depth at grid location k; and RZc and RZd are coefficients supplied as input in the model control file. The coefficients are used to adjust the depth of the root zone extending into bedrock for locations with thin soils. For example, for the modern climate simulations, RZc and RZd were both set to 2, and thus the extension of the root zone into bedrock was limited to locations with soil depth less than four meters. Using Equation 6-17, the root zone extends two meters into bedrock for locations having no soil, one meter into bedrock for locations having two meters soil depth, and 1.5 meters into bedrock for locations having one meter soil depth. The empirical model defined by Equation 6-17 is consistent with the estimated root-zone depth defined in Flint et al. (1996, Table 5) and is derived on the basis of field observations of rooting depth into bedrock, and evaluation of measurements of extraction of water within the estimated root zone in bedrock, using neutron moisture meters.

7.4.5 Estimated Root-Zone Layering and Root-Zone Density

Root-zone layers are defined to represent differences in root-zone density, storage capacity, and hydrologic properties affecting evapotranspiration and percolation within the root zone. The layers are used to model vertical percolation and redistribution of water in the root zone. The top layer is used to model both bare-soil evaporation and shallow transpiration. Three lower root-zone layers, which include two soil layers and the bottom bedrock layer, are used for modeling transpiration only. The thickness of each of the four root-zone layers is variable and is defined by the soil-depth map. The thickness of the bottom bedrock layer, $RZ4^k$, is the extension of the root zone into bedrock, as defined using Equation 6-17 above. The thickness of each of the three soil root-zone layers is defined using:

$$
\begin{aligned}
RZ1^k &= SD^k & SD^k \leq RZa \\
RZ2^k &= 0 \\
RZ3^k &= 0 \\
RZ1k &= Rza & RZa \leq SDk \leq RZb \\
RZ2^k &= SD^k - RZa \\
RZ3^k &= 0 \\
RZ1^k &= RZa & RZb \geq SD^k \\
RZ2^k &= RZb - RZa \\
RZ3^k &= SD^k - RZb
\end{aligned}
\qquad \text{(Eq. 6-18)}
$$

where RZ1 is the top root-zone layer thickness (in meters) for grid cell k; RZ2 is the second soil layer thickness; and RZ3 is the third soil layer thickness. Model coefficients RZa and RZb define the maximum thickness of the soil layers. For example, for the modern climate scenarios, RZa = 0.3 and RZb = 1.5, and thus the maximum thickness of the top layer is 0.3 meter, the maximum thickness of the second layer is 1.2 meters, and the maximum thickness of the third layer is 4.5 meters. According to this model, root zones in upland locations with thin soils less than 1.5 meters deep consist of one or two soil layers and one bedrock layer, while alluvial fan terraces having 6 meters or greater soil thickness have three soil layers and no bedrock layer.

The multi-layered root-zone model represents variable root-zone properties (model control file) between layers by using a set of model coefficients specific to each layer. The model coefficients consist of two root-density-weighting factors for each layer (including the bedrock layer) and are defined in the model control file. These root-density-weighting factors were assumed, but are partially based on field observations of root distributions of various plant types at Yucca Mountain. Soil storage capacities are defined for the three soil layers using the soil-type ID assigned to each grid cell in the geospatial-parameter input file, soil porosity, and soil thickness. The bedrock fracture porosity (a coefficient included in the model control file) and the thickness of the bedrock layer define the storage capacity of the bedrock layer. For all simulations, a fracture porosity of 0.02 was determined for the modern climate during model calibration based on comparisons of simulated versus measured stream flow. This value is consistent with model results from CRWMS M&O (2000a, Section 2.5.2.3). The total water-storage capacity of the root zone is a function of the estimated root-zone depth, soil depth, soil porosity, and the bedrock fracture porosity. Figure 7-3 illustrates the calculated total water-storage capacity of the root zone. Minimum storage capacities of approximately 40 mm occur in upland areas with very thin soils and indicate the root-zone water storage capacity of fractured bedrock. Maximum storage capacities of more than 1,000 mm occur at locations with thick alluvium and no bedrock layer included in the root zone.

The reader is referred to Appendix 1 for detailed description and example of the geospatial input file.

Figure 7-3. Total water-storage capacity of the modeled root zone, including bedrock and soil layers Appendix 3).

8. RESULTS of VALIDATION and INSTALLATION TEST PLANS for INFIL V2.0

The results of performing the Validation Test Plan (VTP) and Installation Test Plan (ITP) validate the functionality and performance of INFIL V2.0. The validation tester for INFIL V2.0 was Jennifer Curtis. The platform for testing was a PC, on a Windows NT 4 operating system. The identification number for the CPU on which the test was run is 3337779850003776. The installation test is run as part of the VTP. The correct installation acceptance/rejection criteria are described in the ITP, 10307-ITP-2.0-00 (Table A2-1 in Appendix 2).

8.1 ACCEPTANCE CRITERIA

As stated in the VTP, the acceptance criterion for Test Sequence(s) O, 1, 2, 3, 4, and 5 is that the conditions (program output(s) stated in each sequence subset(s)) are met. Each condition requires a specific program output. For example, Test Sequence O includes test subsets OA, OB, OC, and OD. Within each subset, one or more conditions (program output(s)) are required. In the case of Test Sequence O, Subset OA, there are 12 conditions (program requirements) that must be met.

Confirmation by a reviewer of correct results is performed by review and/or comparison of output in one or more of the output files identified in the subset conditions. Table A2-2 in Appendix 2 is provided to assist in the technical review process.

8.2 TEST SEQUENCE

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for tests. Any special conditions or modifications made to the input files used for a test case are identified. The model setup is identical to the setup intended for model application, as documented in USGS (2001).

8.2.1 Test Sequence 0: Validation of model functions based on inputs and conditions intended for model application

Test sequence 0 consists of 4 test cases (test 0A through test 0D) used to check that the inputs and input file formats intended for model application are being processed correctly by the program, and that the correct output files and formats are being generated. The program performs several internal calculations as part of the model initialization process during which all model inputs are read in, the root zone layers are defined, and the initial root zone water contents are calculated for all layers at all nodes. In addition to validating that the model inputs are being correctly processed, the test cases in this test sequence are also used to validate that the intended output files are generated according to options defined in the model control file, and that the intended results are included in the output. This test sequence is used only as a general validation of the intended output and also that the various model components have been integrated into the daily water balance calculation as intended. The primary purpose of this test sequence is to validate the program under the same conditions that will be used for the intended model application. A more rigorous validation of specific model functions is provided by other test sequences, but these will use modified model inputs in order to generate the conditions necessary for the test cases.

Test 0A: Validation of Mod3-ppt.dat Daily Climate Input Format

Test description: Test 0A is performed to validate RD requirements 1, 2, 3, 4, 7, 8, 13, 14, 15, and 16 (see Section 2.2). The daily climate input file used to run test 0A is mod3-ppt.dat, which is one of the daily climate input files used to generate results in USGS (2001). The model run period is set to equal the full period defined by mod3-ppt.dat (1/1/1980 – 10/1/95). The geospatial parameter file specified in the model control file is T1.w20. The file T1.w20 is a small subset of the geospatial parameters defined for the full model domain documented in USGS (2001). The file consists of a total of 125 grid nodes, including 75 active nodes and 50 boundary nodes. Boundary nodes are used only as input to the surface water routing algorithm; the nodes are not included in the calculation of daily averages or annual totals, and are not included in the average annual map file. All parameters defined by T1.w20 are fully documented in USGS (2001) (these input parameters are the same as those used to develop the model results documented in USGS (2001)). Soil and bedrock properties for the various soil and rock types defined in the geospatial parameter file are designated in the model control file, and are identical to the properties used to develop model results in USGS (2001).

Test 0A is designed to check that model inputs are correctly read-in and processed, the intended outputs are generated, and the water volume balance is satisfied when using model inputs intended for model application. The test results also indicate consistency between the three primary output files (daily averages, annual totals, and average annual rates are being calculated correctly based on daily results modeled at each grid node). All model inputs used in this test are the same inputs used in model application for developing the lower-bound modern climate and the mean modern climate results documented in USGS (2001).

Test 0B: Validation of 4JA.S01 Daily Climate Input Format

Test description: Test 0b is performed to validate RD requirements 1, 7, 8, 11, 13, 14, and 15 (see Section 2.2). The daily climate input file is 4JA.s01, and the geospatial parameter input file is T1.w20. The file 4JA.s01 is one of the daily climate input files documented in USGS (2001). The test conditions are identical to those defined for test 0a with the exception that the file 4ja.s01 is used for the daily climate input file, the simulation period is set to 100 years, and output file options are modified. The file 4ja.s01 is generated as a stochastic simulation of daily precipitation using the qualified program PPTSIM V1.0, as documented in USGS (2001). The test is used to validate that the input format for 4ja.s01 (which is slightly different from the input format of mod3-ppt.dat) is correctly processed by the program. The test is also used to validate that the water volume balance is satisfied for a 100-year simulation, and that the model results are consistent between the three primary output files. All model inputs used in this test are the same inputs used in model application for developing the lower-bound modern climate and the mean modern climate results documented in USGS (2001).

Table A1-1 of Apendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 0b. There are no special conditions or modifications made to the input files used for this test case. The model setup is identical to the setup intended for model application. The following provides a description of the critical differences in the model control file for test 0b relative to test 0a:

1. The daily climate input file is set to 4ja.s01, and the input format option is set to read in the file format for output generated by PPTSIM V1.0 (PPTFILE = "4ja.s01", IPPTDAT = 1)

2. The simulation period is set to follow the arbitrary 100-year period defined by the time sequence parameters provided by 4ja.s01 (YRBEG = 1, DNBEG = 1, YREND = 100, DNEND = 365)

3. The output options for the annual summary map files are set to generate 10 10-year averages for the 100-year simulation (TYEAR1 = 1, TYEAR2 = 10)

Test 0C: Validation of Rosalia.inp Daily Climate Input Format

Test description: Test 0C is performed to validate RD requirements 1, 3, 4, 5, 7, 8, 11, 13, 14, and 15 (see Section 2.2). The daily climate input file is Rosalia.inp, and the geospatial parameter input file is T1.w20. The test conditions are similar to those defined for test 0B. The file Rosalia.inp is used for the daily climate input file, and the simulation period is set from 1951 through 1997. The file Rosalia.inp is generated as output from the routine DAILY09, which is documented in USGS (2001). The root zone parameters and ET model coefficients are modified to represent an increase in vegetation density and root depths. The test is used to validate that the input format for Rosalia.inp, which includes daily air temperature inputs, is correctly processed by the program. The test includes a validation that the time series defined by Rosalia.inp, which includes missing years due to incomplete records, is processed correctly by the program and that missing years do not cause errors. The test is also used to validate that the daily air temperature inputs are correctly used to model evapotranspiration, snowfall, snowmelt, and sublimation. All model inputs used in this test are the same inputs used in model application for developing the upper-bound glacial transition climate results documented in USGS (2001).

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 0C. There are no special conditions or modifications made to the input files used for this test case. The model setup is identical to the setup intended for model application. The following provides a description of the critical differences in the model control file for test 0C relative to test 0B:

Test 0D: Validation of the Average Annual Map Output File Format for Post-Processing Application using the Software Routine MAPADD20

Test description: Test 0D is performed to validate RD requirements 1 and 6 (see Section 2.2). The daily climate input file is Rosalia.inp. The simulation period is set to 1980 through 1985. For this test, three geospatial parameter input files are used (Jr2.w20, Jr3.w20, and Sc2.w20), and thus 3 separate simulations are run (Test 0D1, Test 0D2, and Test 0D3). With the exception of the geospatial parameter input files, the output file names, and the specified simulation period, all parameters in the model control file are identical to Test 0C. The primary purpose of this test is to validate that the average annual map files (Test0d1.v24, Test0d2.v24, and Test0d3.v24) are in the correct format and can be used as input for the post-processing routine MAPADD20. The test includes an application of the routine MAPADD20, and inspection of the output generated by MAPADD20 to validate that the inputs were correctly processed. This test is only used to validate the output generated by INFIL v2.0. Validation and documentation of the routine MAPADD20 is provided in USGS (2001). All model inputs used in this test are the same inputs used in model application for developing the upper-bound glacial transition climate results documented in USGS (2001).

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for tests 0D1 through 0D3. Results for the three test simulations are obtained, and the output files Testd1.v24, Test0d2.v24, and Test0d3.v24, are defined as input for MAPADD20 using the routine control file MAPADD20.ctl. The following is a listing of the routine control file MAPADD20.ctl that is used for this test case:

mapadd20.ctl: INFIL v2.0 validation test 0d, model gu1-5os-v2-w20 (9/20/99)

```
test0d.out
test0d.dat
test0d.sum
test0d.err
1
3 1 1.0e-08
jr2-gu1-5os-v2-w20
1    test0d1.v24
jr3-gu1-5os-v2-w20
1    test0d2.v24
sc2-gu1-5os-v2-w20
1    test0d3.v24
```

A complete description of the routine MAPADD20, including an explanation of routine functions, intended applications, and a description of input and output files and file formats, is provided in USGS (2001). The model setup for all three simulations used in this test case is identical to the setup intended for model application. The following provides a description of the critical differences in the model control files for test 0D relative to test 0C:

1. The simulation period is set to a 6-year period, 1980 through 1985, within the complete time sequence defined by Rosalia.inp (YRBEG = 1980, DNBEG = 1, YREND = 1985, DNEND = 1)

2. The output options for the annual summary map files are set to generate 1-year totals for each of the 6 years. (TYEAR1 = 0, TYEAR2 = 1)

3. For Test 0D1, the geospatial parameter input file is set to Jr2.w20. For Test 0D2, the geospatial parameter input file is set to Jr3.w20. For Test 0D3, the geospatial parameter input file is set to Sc2.w20. (INFILE = Jr2.w20, Jr3.w20, SC2.w20)

8.2.2 Test Sequence 1: Validation of Infiltration and Net Infiltration Functions using a Multi-layered Root Zone Model

This test sequence consists of 6 tests (test 1a through 1f) used to check the internal water volume balance calculation performed by the program. The test cases provided a basic check that equations 1 and 2 in the RD are satisfied (to within the limitations of machine precision and the number of significant figures carried by the output). All tests performed in this test sequence are based on evaluation of model calculations using only the specified initial conditions for the root zone water content, along with variations in the specified model options and input parameters.

All test conditions are defined by modifying parameter values in the model control file (INFILv2.ctl). Daily precipitation and potential evapotranspiration are set to 0 for all test cases in this test sequence. By de-activating precipitation input, the model results are simplified because the water volume balance calculation is based only on the specified initial condition and water loss from the root zone due to net infiltration. For some test cases, the initial root zone water content is set to exceed soil porosity to ensure that the soil profile is fully saturated. If the initial root zone water content exceeds the root zone storage capacity, excess water is generated, and runoff and surface water routing will occur on the first day of the simulation. Thus, setting the initial water content to exceed the root zone storage capacity is conceptually and numerically equivalent to a large rainfall or snowmelt event on the first day of the simulation, except that potential evapotranspiration is modeled under a clear sky condition.

All test cases in this test sequence use the geospatial parameter input file T1.w20, which is a subset of input parameters used to obtain results documented in USGS (2001). This allows for the validation of spatially distributed model parameters within each test case. The test criteria are based on evaluation of the daily water balance, the water balance for the average annual rates calculated for each model grid node, and on the average results for the entire model grid.

Test 1A: Basic Water Volume Balance Check

Test description: Test 1A is performed to validate RD requirements 1, 7, 13, 14, and 15 (see Section 2.2). The test is designed to check the internal water volume calculation performed by the model. This test is based on the criteria for RD requirement 1 that water cannot be generated or removed internally by the main model algorithm, which calculates daily averages and average annual rates for all terms of the water volume balance. The test results also indicate consistency between the three primary output files (daily averages, annual totals, and average annual rates are being calculated correctly based on daily results modeled at each grid node). Finally, the test indicates that the input from pre-processing routines is being properly read-in, and that the correct output files are being generated properly.

The daily climate input file used to run test 1a is mod3-ppt.dat, which is one of the daily climate input files used to generate results in USGS (2001). This input is used only to drive the model run through the time domain (the PPTFACT term causes all precipitation amounts in mod3-ppt.dat to be 0), and to check that the program is correctly reading in this type of daily climate input format. The model run period is set to equal the full period defined by mod3-ppt.dat (1/1/1980 – 10/1/95). The geospatial parameter file specified in the model control file is T1.w20. The file T1.w20 is a small subset of the geospatial parameters defined for the full model domain documented in USGS (2001). The file consists of a total of 125 grid nodes, including 75 active nodes and 50 boundary nodes. Boundary nodes are not included in the calculation of daily averages or annual totals, and are not included in the average annual map file. All parameters defined by T1.w20 are fully documented in USGS (2001) (these input parameters are the same as those used to develop the model results documented in USGS (2001)). Soil and bedrock properties for the various soil and rock types defined in the geospatial parameter file are designated in the model control file, and are identical to the properties used to develop model results in USGS (2001).

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 1a. The following provides a description of the critical parameters used to define test 2a:

1. All climate inputs are set to 0 in the model control file (Infilv2.ctl) by setting PPTFACT and ETFACT = 0.

2. The root-zone is made impermeable by setting SKSFACT = 0.

3. The underlying bedrock is made impermeable by setting IMBFACT = 0.

4. SDFACT and RKPOR are set to 0, which causes the water storage capacity of the root-zone to be 0.

5. Surface water flow routing is de-coupled from the root-zone sub-model by setting IROUT = 0.

6. The initial soil water content is set to a constant value of 0 by setting IVWCFLG = 0 and VWCFACT = 0.

Test 1B: Basic Water Volume Balance Check with Saturated Initial Conditions

Test description: Test 1b is identical to test 1a, except that the initial soil water content is set to 10 times the wilting point for all soil types designated in T1.w20. The daily climate input file is Mod3-ppt.dat, and the geospatial parameter input file is T1.w20. The thickness of all root zone layers is set to 0 except for layer 3, which is set equal to the soil thickness. This test is a continuation of the basic evaluation of the internal water balance calculation performed by the model. This test is also designed to check that water is not being generated or removed internally by the main model algorithm. The test is a variation of test 1a to show that if precipitation, evapotranspiration, and net infiltration are de-activated, all daily water balance terms will be 0 even when the root is fully saturated (with the exception of the first day when runoff is generated).

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 1b. For test 1b, all parameters are identical to the parameters used for test 1a except for the following modifications:

1. The surface water flow routing component is de-coupled from the root zone model component (IROUT = 0)

2. The simulation time is shortened to 5 years (YREND = 1985, DNEND = 365)

3. Soil depths are set to equal the soil depths designated by the geospatial parameter input file T1.w20 (SDFACT = 1)

4. The thickness of all root zone layers is set to 0, except layer 3, which is set to equal soil depth. This modification causes the root zone to be defined as a 1-layer model that does not extend into underlying bedrock. (RDEPTH1 = 0, RDEPTH2 = 0, RDEPTH4 = 0, RDEPTHF = 2)

5. The initial soil water content is set to 10 times the wilting point for each soil (VWCFACT = 10)

6. The daily map file is set to be generated for the first day of the simulation (IRDAY = 1, NYROUT = 1980)

Test 1C: Basic Water Volume Balance Check with Saturated Initial Conditions

Test description: This test is a continuation of the basic evaluation of the internal water balance calculation performed by the model, and the processing of the geospatial input parameters to develop a multi-layered root zone model. The daily climate input file is Mod3-ppt.dat, and the geospatial parameter input file is T1.w20. The test is a variation of test 1b to show that water is not created or subtracted when net infiltration and surface water processes are enabled using a single layer root zone model. For this test, the initial water content is set equal to 20 times the wilting point of each soil type. To validate that infiltration rates are being correctly calculated throughout the duration of the simulation period, a series of daily map files are generated as output. A positive test result indicates that water is not being generated or removed internally by the code, and that the root zone functions are performing as intended under the specified conditions of the test case.

Test 1C is similar to test 1b, with the following modifications in the model control file:

1. Coupled surface water flow routing is enabled (IROUT = 1)

2. The soil and bedrock hydraulic conductivity for each soil and rock type in the model is set equal to the values defined in the model control file. This allows for net infiltration to occur at the bottom of the root zone. (IMBFACT, SKSFACT = 1)

3. The root zone is modeled as a single layered system, with the thickness of the top layer equal to the soil thickness (RDEPTH1 = 3, RDEPTH2 = 0, RDEPTH4 = 0, RDEPTHF = 0).

4. The initial soil water content is set equal to 20 times the wilting point for each soil type (VWCFACT = 20)

5. A set of 4 daily map files are designated as output files. (NDAYMAP = 4)

Test 1D: Basic Water Volume Balance Check with Layered Root Zone

Test description: This test is a continuation of the basic evaluation of the internal water balance calculation performed by the model, the processing of the geospatial input parameters to develop a multi-layered root zone model, and the intended function of the multi-layered root zone model. The daily climate input file is Mod3-ppt.dat, and the geospatial parameter input file is T1.w20. Test 1d is a variation of test 1c to show that the water volume balance is satisfied when the root zone is modeled as a layered system. A positive test result indicates that water is not being generated or removed internally by the code under the specified conditions of the test case, and that daily net infiltration rates are correctly calculated by the program.

Test 1D is similar to test 1c, with the following modification in the model control file:

The root zone is modeled as a multi-layered system by setting RDEPTH = 0.1, RDEPTH2 = 0.2, RDEPTH4 = 0.5, and RDEPTHF = 1.

Test 1E: Basic Water Volume Balance Check with Layered Root Zone
Test description: This test is a continuation of the basic evaluation of the internal water balance calculation performed by the model, the processing of the geospatial input parameters to develop a multi-layered root zone model, and the intended function of the multi-layered root zone model.

The daily climate input file is Mod3-ppt.dat, and the geospatial parameter input file is T1.w20. Test 1e is identical to test 1d, except that an effective storage capacity term of 0.10 is enabled for the rock layer in the root zone profile. This is accomplished by changing RKPOR from 0 to 0.1 (all other parameters are left unchanged). The initial condition for the rock layer is always set to 0 (the specified initial conditions only affect the soil water content), and thus some of the excess water developed by the specified initial soil water content is infiltrated into the available storage capacity of the rock layer. The effective storage capacity of the bedrock layer is defined based on the effective bedrock porosity term (RKPOR) and the thickness of the bedrock layer, which is modeled as an empirical function of soil thickness using the parameters RDEPTH4 and RDEPTHF. The purpose of Test 1e is to show that the water volume balance is satisfied when the root zone is modeled as a layered system, and the bedrock layer (layer 4) is given an effective storage capacity. The effective storage capacity of the bedrock layer allows evapotranspiration from the bedrock layer before net infiltration is calculated, and thus the root zone is allowed to extend into bedrock. A positive test result indicates that water is not being generated or removed internally by the code under the specified conditions of the test case, and that daily net infiltration rates are correctly calculated by the program.

Test 1E is similar to test 1d, with the following modification in the model control file:

The root zone is modeled as a multi-layered system with root extending into the bottom bedrock layer by setting RKPOR = 0.1 (10% effective porosity).

Test 1F: Basic Water Volume Balance Check with Layered Root Zone
Test description: This test is a continuation of the basic evaluation of the internal water balance calculation performed by the model, the processing of the geospatial input parameters to develop a multi-layered root zone model, and the intended function of the multi-layered root zone model.

The daily climate input file is Mod3-ppt.dat, and the geospatial parameter input file is T1.w20. Test 1f is identical to test 1e, except that the soil saturated hydraulic conductivity has been decreased by 4 orders of magnitude. The purpose of this test is to validate that net infiltration and infiltration through the root zone is dependent on soil properties as well as the soil or bedrock underlying the root zone. A positive test result indicates that the multi-layered root zone model is functioning as intended.

Test 1F is similar to test 1e, with the following modification in the model control file:

The soil saturated hydraulic conductivity of the root zone is decreased by 4 orders of magnitude by setting SKSFACT = 0.0001.

8.2.3 Test Sequence 2: Validation of Evapotranspiration Functions Coupled with Infiltration and Net Infiltration using a Multi-layered Root Zone

Test sequence 2 consists of 11tests (test 2a through test 2k) used to evaluate the internal water volume calculation performed by the program, in response to a specified set of initial conditions and daily evapotranspiration conditions. The test sequence is designed to show that the model components applied to calculate potential evapotranspiration, evaporation, transpiration, evapotranspiration, infiltration (through a layered root zone), and net infiltration, are performing the intended functions and that specific components of the root zone water volume balance calculations are being correctly executed. The modeled root zone functions are evaluated based on variations in parameters defining root zone layering, root density, vegetation cover, and both soil and bedrock properties.

The test sequence is similar to test sequence 1 in that the simulations set daily precipitation input to 0, so that each test case is simplified to show the model response to the initial water content of the root zone. By de-activating precipitation input, the model results are simplified because the water volume balance calculation is based only on the specified initial condition and water loss from the root zone due to net infiltration and evapotranspiration. For some test cases, the initial root zone water content is set to exceed soil porosity to ensure that the soil profile is fully saturated. If the initial root zone water content exceeds the root zone storage capacity, excess water is generated, and runoff and surface water routing will occur on the first day of the simulation. Thus, setting the initial water content to exceed the root zone storage capacity is conceptually and numerically equivalent to a large rainfall or snowmelt event on the first day of the simulation, except that potential evapotranspiration is modeled under a clear sky condition.

All test conditions are defined by modifying parameter values in the model control file (INFILv2.ctl). Some test cases require modifications to the parameters in the daily climate input file Mod3-ppt.dat or the parameters in the geospatial parameter file T1.w20. The modified versions of Mod3-ppt.dat are Test2d.dat and Test2e.dat, and the modifications are made to the day of year number. The modified version of T1.w20 is T1a.w20, where the parameters for soil type, soil depth, and rock type are set to uniform values.

Test 2A: Potential Evapotranspiration Functions

Test description: This test case provides a basic check of the potential evapotranspiration function. The daily climate input file is Mod3-ppt.dat and the geospatial parameter input file is T1.w20. Test conditions are set so that there is no water available for evapotranspiration in the layered root zone. This is accomplished by disabling precipitation input and setting the initial soil water content to equal the wilting point (note: setting the initial water content to less than the wilting point will cause meaningless output on the first day of the simulation period). All water balance components should be 0 throughout the simulation period, even though evapotranspiration and net infiltration are allowed, and the root zone is modeled as a multi-layered system. Potential evapotranspiration should be correlated with air temperature and the day of year. A positive test result indicates that the potential evapotranspiration component of the model is functioning as intended.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2a. Test case 2a uses the same model inputs as test case 0a with the following modifications to the model control file:

1. The simulation period is shortened to 6 years (YREND = 1985, DNEND = 365)

2. Precipitation input is disabled (PPTFACT = 0)

3. Initial conditions are set to equal the wilting point for all soil layers (VWCFACT = 1.0)

Test 2B: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2a in which the seasonal variation in air temperature is removed by setting daily air temperature to a constant value equal to the average daily temperature in test 2a. The daily climate input file is Mod3-ppt.dat and the geospatial parameter input file is T1.w20. This test is used to validate the intended effect of air temperature on potential evapotranspiration. The test results should indicate a decrease in the seasonal variability of modeled potential evapotranspiration, and a slight decrease in the average annual potential evapotranspiration rate (the effect of air temperature on modeled potential evapotranspiration is non-linear).

In addition to testing the potential evapotranspiration function, test 2b is used to perform a general validation of the integrated response of the evapotranspiration, the surface water routing, and the net infiltration functions based on the initial root zone water content and geospatial model parameters intended for model application. A positive test result indicates that the evapotranspiration function is performing as intended when integrated with other model components and when used with model parameters intended for model application.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2b. All input parameters values are identical to the values used in test 2a with the exception of the following modifications:

1. Daily air temperature is set to a constant value (ATEMP2 = 0)

2. The initial root zone water content is set to 20 times the wilting point for all soil layers (VWCFACT = 20)

Test 2C: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2b in which the average daily air temperature is reduced to approximately 0 degrees C. The daily climate input file is Mod3-ppt.dat and the geospatial parameter input file is T1.w20. The decrease in air temperature should cause a decrease in both the potential evapotranspiration rate and the actual evapotranspiration rate, along with an increase in net infiltration. Seasonal variability in air temperature is still disabled and thus daily air temperature should be constant for each day of the simulation. Daily potential evapotranspiration should still be correlated to the day of year, and annual potential evapotranspiration should still show variability across model nodes due to variability in topographic parameters included in the geospatial parameter file. A positive test result validates that the potential evapotranspiration and the evapotranspiration model components are functioning as intended.

In addition to testing the potential evapotranspiration function, test 2c is a continuation of a general validation of the integrated response of the evapotranspiration, the surface water routing, and the net infiltration functions based on the initial root zone water content and geospatial model parameters intended for model application. A positive test result indicates that the evapotranspiration function is performing as intended when integrated with other model components and when used with model parameters intended for model application.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2c. All input parameters values are identical to the values used in test 2b with the exception of the following modification:

Daily air temperature is set to a constant value of approximately 0 degrees C (ATEMP1 = 0.0).

Test 2D: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2c in which the daily climate input file (mod3-ppt.dat) is modified (the modified file is Test2d.dat) so that the day of year number is a constant value of 355 (December 21st) for all days simulated. The geospatial parameter input file is T1.w20. This test is used to validate the intended effect of topographic parameters on modeled potential evapotranspiration by disabling the effects of variable daily air temperature and the day of year. The test conditions force a minimum sun angle (thus maximizing shading effects from surrounding topography) for all days simulated, and the duration of daylight hours is at a minimum. The expected result is an increase in the spatial variability of potential evapotranspiration relative to results obtained for all previous test cases in this test sequence (tests 2a, 3b, 2c). For the period 1980-85, the daily and annual potential evapotranspiration rates should be less relative to results obtained for test 2c for all days and years simulated, while the net infiltration rate should be higher for this same period. A positive test result indicates that the solar radiation algorithm of the potential evapotranspiration model component is functioning as intended, and the slope, aspect, and 36 blocking ridge angles defined for each model node in the geospatial parameter input file are being processed correctly by the model.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2d. All input parameters values are identical to the values used in test 2c with the exception of the following modification:

The daily climate input file is set to Test2d.dat. (PPTFILE = Test2d.dat)

Test 2E: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2c in which the daily climate input file (mod3-ppt.dat) is modified (the modified file is Test2e.dat) so that the day of year number is a constant value of 171 (June 19th) for all days simulated. The daily climate input file is Mod3-ppt.dat and the geospatial parameter input file is T1.w20. This test is used to validate the intended effect of topographic parameters on modeled potential evapotranspiration by disabling the effects of variable daily air temperature and the day of year. The test conditions force a maximum sun angle (thus minimizing shading effects from surrounding topography) for all days simulated, and the duration of daylight hours is at a maximum. The expected result is a decrease in the spatial variability of potential evapotranspiration relative to results obtained for all previous test cases in this test sequence (tests 2a, 2b, 2c, and 2d). For the period 1980-85, the daily and annual potential evapotranspiration rates should be greater relative to results obtained for test 2c for all days and years simulated, while the net infiltration rate should be lower for this same period. A positive test result indicates that the solar radiation algorithm of the potential evapotranspiration model component is functioning as intended, and the slope, aspect, and 36 blocking ridge angles defined for each model node in the geospatial parameter input file are being processed correctly by the model.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2e. All input parameters values are identical to the values used in test 2d with the exception of the following modification:

The daily climate input file is set to Test2e.dat. (PPTFILE = Test2e.dat)

Test 2F: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2a in which the geospatial parameter input file (t1.w20) is modified to set a uniform soil depth, soil type, and rock type for all model nodes (the modified file is T1a.w20). The daily climate input file is Mod3-ppt.dat. Initial conditions are set to fully saturate the root zone profile, while daily precipitation input is still disabled, and daily potential evapotranspiration is set to a constant rate of 5 mm/day. The root zone parameters are similar to parameters used in model application for the modern climate simulations in USGS (2001). Soil saturated hydraulic conductivity for the uniform soil type 10 is increased to allow free drainage at field capacity. To facilitate a hand calculation check of the root zone water contents, both the wilting point and the field capacity for soil type 10 are set to 0.1, and the porosity is set to 0.3 by modifying the soil properties parameters in the model control file. A uniform rock type is defined for the model grid (rock type 500 in the model control file), and the bulk saturated bedrock hydraulic conductivity is set to 1 mm/day. To facilitate checking of actual evapotranspiration rates relative to potential evapotranspiration rates, the alpha parameter in the modified Preistley-Taylor function used in the evapotranspiration model is set to 1.0 for bare soil, bare rock, vegetated soil, and vegetated rock.

The purpose of this test case is to validate that the evapotranspiration model component of the multi-layered root zone model is functioning as intended in terms of a dynamic partitioning of water contents and evapotranspiration rates, integrated with surface water run-on, root zone percolation, and net infiltration. The test criteria are designed to show that when soil permeability is high, drainage into the lower root zone layers maintains full saturation for those layers even though evapotranspiration losses and net infiltration are removing water from the root zone system. In addition, the root is modeled as having a decreasing root density with depth, so that evapotranspiration rates are maximized at the top layer, as long as the water content of the top layer remains relatively high. Through time the top layers dry out more rapidly than the bottom layers of the root zone (especially if free drainage is allowed into the bottom layers). As the water content for the top layers approaches the wilting point, the evapotranspiration rates for the bottom layers increases because a dynamic weighting function allows evapotranspiration to adjust to the distribution of water contents across the root zone layers.

This test is designed to show the expected changes in water contents for root zone layers based on inspection of a series of daily map files, in conjunction with inspection of the daily output file. A series of 7 daily map files are generated by setting user-defined options in the model control file. A positive test result indicates that the dynamic evapotranspiration functions in the multi-layered root zone model are performing as intended.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2f. All input parameters values are identical to the values used in test 2a with the exception of the following modifications:

1. Daily potential evapotranspiration is set to a constant rate of 5 mm/day (IETTEST = 1, ETTEST = 5).

2. The alpha parameter for bare soil evaporation is changed from 1.04 to 1 (BARSOIL2 = 1).
3. The initial water content is set to 4 times the soil wilting point (VWCFACT = 4).
4. A uniform soil depth, soil type, and rock type is defined for all model nodes by modifying the geospatial parameter input file T1.w20 (the modified file is named T1a.w20). In the modified geospatial parameter input file, the soil type is set to 10, and the rock type is set to 500 (INFILE = T1a.w20).
5. The number of daily map output files is set to 7 (NDAYMAP = 7). The simulation days for which each successive daily map file is generated are: 01/01/80, 01/02/80, 01/10/80, 2/26/80, 2/27/80, 2/28/80, and 12/31/85 (IRDAY(1) = 1, NYROUT(1) = 1980, IRDAY(2) = 2, NYROUT(2) = 1980, IRDAY(3) = 10, NYROUT(3) = 1980, IRDAY(4) = 57, NYROUT(4) = 1980, IRDAY(5) = 58, NYROUT(5) = 1980, IRDAY(6) = 59, NYROUT(6) = 1980, IRDAY(7) = 365, NYROUT(7) = 1985).
6. For soil type 10, the wilting point is set to 0.1, the field capacity is set to 0.2, and the porosity is set to 0.3 (FIELDCAP = 0.1, SOILRESID = 0.1, SOILPOR = 0.3).
7. For soil type 10, the wilting point is set to 0.1, the field capacity is set to 0.2, and the porosity is set to 0.3 (FIELDCAP = 0.1, SOILRESID = 0.1, SOILPOR = 0.3).
8. Rock type 500 is added to the model control file (NROCKID = 130). The bulk saturated hydraulic conductivity of rock type 500 is set to 1 mm/day (IMBIBE(500) = 1.0).

Test 2G: Potential Evapotranspiration and Evapotranspiration
Test description: This test case is a modified version of test 2f in which the soil saturated hydraulic conductivity is reduced by a factor of 0.000001. This modification decreases the rate of drainage of the saturated soil profile into the underlying rock layer (which has an effective water content of 0 at the start of the simulation). The daily climate input file for this test is Mod3-ppt.dat, and the geospatial parameter input file is T1a.w20. For the conditions defined in this test case, transpiration from the rock layer continually removes the water that slowly infiltrates from the overlying soil layers. The transpiration prevents the water content of the rock layer from reaching the effective storage capacity of 30 mm, and the occurrence of net infiltration is prevented.

The purpose of this test case is to validate that the transpiration model component of the multi-layered root zone model is functioning as intended in terms of a dynamic partitioning of water contents and transpiration rates, integrated with surface water run-on, root zone percolation, and net infiltration. Although drainage into the bottom bedrock layer of the root zone is allowed, the drainage rate is too slow to allow the water content of the bedrock layer to reach the effective storage capacity. Thus, the test conditions are designed to show that when soil permeability is low, transpiration "catches up" with the water percolating through the root zone and eventually removes all water from the bottom root zone layer before net infiltration can occur. A positive test result indicates that the dynamic transpiration functions in the multi-layered root zone model are performing as intended.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2g. All input parameters values are identical to the values used in test 2g with the exception of the following modification:

The soil saturated hydraulic conductivity is reduced by a factor of 0.000001 (SKSFACT = 0.000001)

Test 2H: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2g in which the soil saturated hydraulic conductivity is increased by a factor of 10 (a factor of 0.00001 decrease relative to the soil saturated hydraulic conductivity used for test 2f). This modification slightly increases the rate of drainage of the saturated soil profile into the underlying rock layer. For the conditions defined in this test case, transpiration from the rock layer continually removes the water that slowly infiltrates from the overlying soil layers, but the effective storage capacity of the rock layer is eventually filled. Net infiltration does not occur until approximately 1 month after the beginning of the simulation, and only lasts for a period of approximately 2 weeks.

The purpose of this test case is to validate that the transpiration model component of the multi-layered root zone model is functioning as intended in terms of a dynamic partitioning of water contents and transpiration rates, integrated with surface water run-on, root zone percolation, and net infiltration. Although drainage into the bottom bedrock layer of the root zone is allowed and net infiltration does occur, the total net infiltration depth is relatively small because most water is removed by transpiration as the water slowly drains through the rock layer of the root zone.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2h. All input parameters values are identical to the values used in test 2g with the exception of the following modification:

The soil saturated hydraulic conductivity is reduced by a factor of 0.00001 (SKSFACT = 0.00001)

Test 2I: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2h in which the potential evapotranspiration rate is reduced to 2 mm/day. This modification is intended to greatly increases the duration of net infiltration, but should not greatly increase the net infiltration rate because this is still limited by the low soil permeability, in addition to transpiration from the rock layer. The occurrence of net infiltration should still be delayed, but the net infiltration rate should be slightly greater than the results for test 2h because transpiration is reduced and thus removes a smaller fraction of water from net infiltration. The purpose of this test case is to validate that the transpiration model component of the multi-layered root zone model is functioning as intended in terms of a dynamic partitioning of water contents and transpiration rates, integrated with surface water run-on, root zone percolation, and net infiltration. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2i. All input parameters values are identical to the values used in test 2h with the exception of the following modification:

1. The potential evapotranspiration rate is set to 2 mm/day (ETTEST = 2.0)

Test2J: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2i in which the soil depth is increased to 2 meters. The root zone layering is defined to include all 4 layers (the 3 soil layers and the underlying rock layer all have layer a thickness greater then 0 meters). Potential evapotranspiration is held constant at 2

mm/day. The root density weighting factors are defined to represent very low vegetation cover, with roots extending into the top layer only. The field capacity for the soil layers is increased from 0.1 to 0.2 to allow testing of the root density weighting functions. Net infiltration should be maximized because transpiration is greatly reduced. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. The purpose of this test case is to validate that the transpiration model component of the multi-layered root zone model is functioning as intended, and that root density is correctly controlled using parameters in the model control file.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2j. All input parameters values are identical to the values used in test 2i with the exception of the following modifications:

1. The soil depth is increased to 2 meters (SDFACT = 2m)
2. The root density weighting factors are set to 1 for the top layer, and to 0 for all other layers. (ROOTF1 = 1, ROOTF2 = 0, ROOTF3 = 0, ROOTF4 = 0, MAXWGT1 = 1, MAXWGT2 = 0, MAXWGT3 = 0, MAXWGT4 = 0)
3. Layer 3 is set to a thickness of 1 meter, and the rock layer is set to a thickness of 2 meters. (RDEPTH1 = 0.3, RDEPTH2 = 1, RDEPTH4 = 3, RDEPTHF = 2)
   This confines the root zone to the top layer only.
4. The soil field capacity for soil type 10 is set 0.2 (FIELDCAP(10) = 0.2)
5. The soil saturated hydraulic conductivity is set to 1E-4 kg*sec/m^3

Test2K: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2j in which the root density weighting factors are defined so that bare-soil evaporation does not occur and transpiration occurs from layers 2 and 4 only. Net infiltration should be decreased relative to results for test 2j. The purpose of this test case is to validate that the transpiration model component of the multi-layered root zone model is functioning as intended, and that root density is correctly controlled using parameters in the model control file. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file is T1a.w20.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2k. All input parameters values are identical to the values used in test 2g with the exception of the following modifications:

The root density weighting factors are set to 1 for the second soil layer and the rock layer (layers 2 and 4), and 0 for the top layer and the third soil layer (evapotranspiration is disabled for those layers). (ROOTF1 = 0, ROOTF2 = 1, ROOTF3 = 0, ROOTF4 = 1, MAXWGT1 = 0, MAXWGT2 = 1, MAXWGT3 = 0, MAXWGT4 = 1)

8.2.4 Test Sequence 3: Validation of Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test sequence 3 consists of 7 tests (test 3a through test 3g) used to evaluate the internal water volume calculation performed by the program, in response to a specified set of initial conditions and controlled daily precipitation input. The test conditions are similar to those used in test sequence 2, except that daily precipitation input is incorporated, and for all test cases the initial root zone water content is set to the wilting point water content for the root zone. Thus, where test sequence 2 is used to validate model functions in terms of initial wet conditions and the drying out of the root zone, test sequence 3 is designed to validate model functions in terms of initially dry conditions and the wetting up of the root zone. The test sequence is designed to show that the model components applied to calculate potential evapotranspiration, evaporation, transpiration, evapotranspiration, infiltration (through a layered root zone), and net infiltration, are performing the intended functions and that specific components of the root zone water volume balance calculations are being correctly executed. The modeled root zone functions are evaluated based on variations in parameters defining root zone layering, root density, vegetation cover, and both soil and bedrock properties. For most test cases, model results should indicate that a steady state condition has been reached in response to a steady state precipitation input.

All test conditions are defined by modifying parameter values in the model control file (INFILv2.ctl). All test cases require a modified version of the geospatial parameter file T1.w20. The modified version of T1.w20 is T1a.w20, where the parameters for soil type, soil depth, and rock type are set to uniform values. Although all test cases use the daily climate input file Mod3-ppt.dat to drive the simulation through time, the daily precipitation input is set to a constant rate by using model options in the model control file.

Test 3A: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test case uses the same setup for root zone layering and soil depth that was used in tests 2h – 2k (4-layered root zone system, with 2 meters of soil and 2 meters of rock). The thickness of the top soil layer is set to 0.3 meter, the middle layer is set to 0.7 meter, and the third layer is to 1 meter. Evapotranspiration is disabled, and thus the purpose of the test is to validate that once the soil profile and bedrock layer have become fully saturated, daily precipitation input must equal the sum of net infiltration and outflow. The net infiltration rate must equal the bulk saturated hydraulic conductivity of the rock layer, because the precipitation rate is set to exceed the bedrock conductivity.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3a. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 2k with the exception of the following modifications:

1. Coupled flow routing is enabled for the last day of the simulation (OPTMASSB = 0)
2. Daily precipitation input is set to a constant value of 10 mm/day (IPPTEST = 1, PPTTEST = 10, PPTFACT = 1)
3. Daily evapotranspiration is disabled (IETTEST = 0, ETFACT = 0)
4. Initial conditions are set to the soil wilting point water content (VWCFACT = 1)

Test 3B: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test uses the same setup as test 3a except that the soil saturated hydraulic conductivity is reduced by a factor Of 0.0001 to prevent net infiltration from occurring within the simulation period. The root zone very gradually increases in saturation at a rate determined by storm duration and the soil saturated hydraulic conductivity (0.0001 x 84.672 = 0.0084672 mm/day). Storm duration is assumed to be 2 hours for summer storms (occurring between days 183 and 247 and 12 hours for winter storms (occurring between the days of 184 and 246 of the following year). If runoff is generated, the duration of surface water flow is assumed equivalent to storm duration, but occurs after precipitation. Thus, if both infiltration of precipitation and infiltration of run-on are allowed, the maximum infiltration rate for a summer storm should be 2 x (0.0084672/12) = 0.001411 mm/day and the maximum infiltration rate for a winter storm should be 2 x (0.0084672/2) = 0.0084672. The purpose of the test is to validate that net infiltration rate is limited by both the permeability of the soil and the permeability of the underlying bedrock. In addition, the test is used to validate that net infiltration does not occur until the effective storage capacity of the bedrock layer has been exceeded (if the root zone extends into bedrock), and that storm duration is being correctly incorporated into the calculation of maximum infiltration rates into the root zone profile.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3b. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 3a with the exception of the following modification:

1. Coupled flow routing is disabled for the last day of the simulation (OPTMASSB = 1).

2. The saturated hydraulic conductivity of the soil is reduced by 4 orders of magnitude (SKSFACT = 0.0001).

Test 3C: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test uses the same setup as test 3b except that the soil depth is set to a uniform depth of 0.1 meters and the root zone storage capacity in the bedrock layer is set to 0.001. By setting the soil depth to 0.1 meters, the thickness of soil layers 2 and 3 is 0 meters, the thickness of the top soil layer is 0.1 meters, and the thickness of the bottom rock layer is 2.95 meters. Thus, the storage capacity of the soil layer is 30 mm, and the storage capacity of the rock layer is 2.95 mm. The purpose of the test is to validate that net infiltration will not occur until the root zone storage capacity in the bedrock layer has been exceeded, and that net infiltration rate is limited by the permeability of the soil as well as the permeability of the underlying bedrock. The test conditions are designed to show that after the root zone profile has been fully saturated and net infiltration is allowed to occur, the net infiltration rate is limited by the minimum saturated hydraulic conductivity of the root zone (as defined by either soil or bedrock). In this case, the minimum hydraulic conductivity is defined by the soil. A positive test result will show that once the water content of the root zone is at full capacity, steady state conditions are maintained for the remainder of the simulation.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3c. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 3b with the exception of the following modification:

1. Soil depth is set to 0.1 meters (SDFACT = 0.1)

2. The effective storage capacity of the bedrock layer is set to 0.001 (RKPOR = 0.001)

Test 3D: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test uses the same setup as test 3c except that the daily potential evapotranspiration rate is set to 2 mm/day for all days simulated. The purpose of the test is to validate that transpiration removes water from the bottom of the root zone, which in this case includes the bedrock layer, before net infiltration is calculated. For these test conditions, the potential evapotranspiration rate is set to 2 mm/day. Because the root zone density parameters for the soil layer are set to 0, only transpiration from the rock layer can occur. The transpiration rate cannot exceed the maximum infiltration rate into the rock layer, which in this case is defined by the saturated hydraulic conductivity of the soil overlying the rock layer. As the water content of the rock layer increases, the transpiration rate also increases. When the transpiration rate equals the infiltration rate, steady state conditions are maintained for the remainder of the simulation.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3d. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 3c with the exception of the following modifications:

1. The potential evapotranspiration rate is set to 2 mm/day (IETTEST = 1, ETTEST = 2)

2. The root density parameters for the top soil layer are set to 0 (ROOTF1 = 0, MAXWGT1 = 0)

Test 3E: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test uses the same setup as test 3d except that the daily potential evapotranspiration rate is set to 5 mm/day, the soil depth is increased to 1 meter, and the bedrock bulk saturated hydraulic conductivity is increased to 5 mm/day. A soil thickness of 1 meter defines 2 soil layers in the root zone, with a 0.3 meter thick top soil layer and a 0.7 meter thick bottom soil layer. The thickness of the rock layer is reduced to 2.5 meters. The root density terms are set to 0 for both soil layers, which forces all evapotranspiration to occur as transpiration only from the rock layer. The purpose of the test is to validate that transpiration removes water from the bottom of the root zone, which in this case includes the bedrock layer, before net infiltration is calculated. A positive result indicates that the transpiration rate exceeds the net infiltration rate because all transpiration is forced to occur in the bottom rock layer, and transpiration is calculated before net infiltration.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3e. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 3d with the exception of the following modifications:

1. The potential evapotranspiration rate is set to 5 mm/day (IETTEST = 1, ETTEST = 5).
2. The root density parameters for the top 2 soil layers are set to 0 (ROOTF1 = 0, ROOTF2 = 0, MAXWGT1 = 0, MAXWGT2 = 0).
3. The bedrock bulk saturated hydraulic conductivity is increased to 5 mm/day (IMBFACT = 5).
4. The soil thickness is set to a uniform thickness of 1 meter (SDFACT = 1).
5. The soil saturated hydraulic conductivity is set to 84.672 mm/day (SKSFACT = 1).

Test 3F: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test uses the same setup as test 3e except that the root zone density terms are set to allow evapotranspiration from the top soil layer and transpiration from the second soil layer. Transpiration from the rock layer is also allowed but is reduced relative to conditions for test case 3e. For this test case, both the evapotranspiration rate and the net infiltration rate should increase relative to test case 3e, while the runoff rate decreases relative to results for test 3e. The purpose of the test is to validate that the transpiration and net infiltration terms are calculated before the runoff term when runoff is generated because the root zone profile has become fully saturated. A positive result also indicates that when transpiration removes water from the soil profile, surface water run-on can infiltrate into the soil profile during the routing process. The purpose of the test is also to validate that the daily root-zone mass balance is satisfied under conditions involving a steady precipitation and potential evapotranspiration rate, with the precipitation rate exceeding the combined potential evapotranspiration and maximum net infiltration rates. For these test conditions, steady state conditions should be established once the root zone is fully saturated.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3f. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 3e with the exception of the following modifications:

The root density parameters for the top 2 soil layers are set to 1, and the root density parameters for the bottom rock layer are reduced to 0.1 (ROOTF1 = 1, ROOTF2 = 1, ROOTF4 = 0.1, MAXWGT1 = 1, MAXWGT2 = 1, MAXWGT = 0.1).

Test 3G: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test uses the same setup as test 3f except that the soil thickness is increased to 2 meters at all nodes. The increase in soil depth decreases the thickness of the rock layer to 2 meters. The soil profile is divided into 3 root zone layers; a top layer having a thickness of 0.3 meters, a second layer having a thickness of 0.7 meters, and a bottom soil layer having a thickness of 1 meter. Thus, the root zone is modeled as a 4-layered profile having a total thickness of 4 meters.

In addition to increasing the soil thickness, the root zone density terms are set to define a decreasing root density with depth. Although transpiration from the rock layer is enabled, the root density is reduced by an order of magnitude relative to the root density used for test 3f. The purpose of the test is to validate that the transpiration and net infiltration terms are calculated before the runoff term when runoff is generated because the root zone profile in a 4-layered root zone system has become fully saturated. The purpose of the test is also to show that when the infiltration rate through the root zone profile exceeds the bedrock bulk saturated hydraulic conductivity, the bottom root zone layers become fully saturated first, while the water content of the top soil is maintained at slightly less than field capacity. A positive test result should indicate that both evapotranspiration and net infiltration are increased relative to results obtained for test 3f, while the runoff and run-on terms are reduced. Evapotranspiration should increase because the thickness of the root zone has been increased. Net infiltration should increase because the root density has been decreased in the rock layer. For these test conditions, steady state conditions should be established once the root zone is fully saturated.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3g. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 3f with the exception of the following modifications:

1. The soil thickness is increased to 2 meters for all nodes (SDFACT = 2).
2. The root density parameters for the top soil layer are set to 1 (ROOTF1 = 1, MAXWGT1 = 1).
3. The root density parameters for the second soil layer are set to 0.5 (ROOTF2 = 0.5, MAXWGT2 = 0.5).
4. The root density parameters for the third soil layer are set to 0.1 (ROOTF3 = 0.1, MAXWGT3 = 0.1).
5. The root density parameters for the rock layer are set to 0.01 (ROOTF4 = 0.01, MAXWGT4 = 0.01).
6. The effective water storage capacity of the rock layer is increased (RKPOR = 0.02)

8.2.5 Test Sequence 4: Validation of Evapotranspiration, Infiltration, Net Infiltration, and Surface Water Routing Functions in Response to Variable Daily Precipitation Input and Geospatial Parameters

Test sequence 4 consists of 6 tests (test 4a through test 4f) used to evaluate the internal water volume calculation performed by the program, in response to a specified set of initial conditions, controlled daily precipitation input, and specified geospatial input parameters. The test conditions are similar to those used in test sequence 3, except that variable daily precipitation input is incorporated using modified versions of the daily climate input file mod3-ppt.dat. For all test cases the initial root zone water content is set to the wilting point water content for the root zone. All test conditions are defined by modifying parameter values in the model control file (INFILv2.ctl). All test cases require a modified version of the geospatial parameter file T1.w20, T1b.w20, where the parameters for soil type, soil depth, and rock type are specified separately for upland and channel nodes. Two different soil depths are defined using the geospatial input file T1b.w20. The "upland" soil depth is set to 1 meter for all model nodes having less than 5 upstream nodes. The "channel" soil depth is set to 6 meters for all model nodes having 5 or more upstream nodes. A unique soil type and rock type is defined for upland and channel nodes. All upland nodes are assigned soil type 10 and rock type 500, whereas all channel nodes are assigned soil type 11 and rock type 400. The hydrologic properties for these fictitious soil and rock types are controlled using the model parameters in the model control file.

The test sequence is designed to show that the model components applied to calculate potential evapotranspiration, evaporation, transpiration, evapotranspiration, infiltration (through a layered root zone), and net infiltration, are performing the intended functions and that specific components of the root zone water volume balance calculations are being correctly executed. The modeled root zone functions are evaluated based on variations in parameters defining root zone layering, root density, vegetation cover, and both soil and bedrock properties.

Test 4A: Infiltration and Coupled Surface Water Flow Routing
Test description: The conditions for test case 4a are defined by setting the bedrock bulk saturated hydraulic conductivity to 0 mm/day for all nodes and by disabling evapotranspiration.

The purpose of the test is to validate that coupled surface water flow routing is initiated when the water storage capacity of the root zone is exceeded for any node in the model domain. For these test conditions, outflow from the watershed does not occur when runoff is initiated because the channel nodes have enough available storage capacity to allow the routed surface water to infiltrate. Because evapotranspiration and net infiltration are disabled, runoff must equal outflow once the root zone has become fully saturated.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 4a. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1b.w20. All input parameters values are identical to the values used in test 3g with the exception of the following modifications:

1. Using the modified geospatial parameter input file T1b.w20, the soil thickness is set to 1 meter for upland nodes, and 6 meters for channel nodes (SDFACT = 1).

2. Using the modified geospatial parameter input file T1b.w20, the soil type is set to 10 for all upland nodes, and 11 for all channel nodes, where a channel node is defined as any node with 5 or more upstream nodes.

3. Using the modified geospatial parameter input file T1b.w20, the rock type is set to 500 for all upland nodes, and 400 for all channel nodes, where a channel node is defined as any node with 5 or more upstream nodes.

4. Evapotranspiration is disabled (IETTEST = 0, ETFACT = 0).

5. Net Infiltration is disabled (IMBFACT = 0)

6. The effective bedrock porosity is set to 0.1 (RKPOR = 0.1)

Test 4B: Infiltration, Net Infiltration, and Coupled Surface Water Flow Routing
Test description: This test uses the same setup as test 4a except that the bedrock bulk saturated hydraulic conductivity for channel nodes is set to 5 mm/day. The soil saturated hydraulic conductivity is increased by a factor of 1000, and the effective surface water flow area is set to 1. These conditions allow all run-on to infiltrate at all model nodes as long as the root zone is not fully saturated. The

purpose of the test is to validate that coupled surface water flow routing is initiated when the water storage capacity of the root zone is exceeded for any node in the model domain. In addition, a positive test result indicates that even though runoff is generated and routed downstream as run-on, the occurrence of outflow from the watershed is dependent on the available root zone storage capacity and the hydraulic conductivity of the soil and bedrock. For these test conditions, outflow from the watershed does not occur when runoff is initiated because the channel nodes have enough available storage capacity to allow the routed surface water to infiltrate, and the effective soil hydraulic conductivity is not a limiting factor. Although net infiltration at channel nodes decreases the outflow rate relative to test case 4a, the bedrock bulk saturated hydraulic conductivity is not high enough to prevent outflow from the watershed.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 4b. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1b.w20. All input parameters values are identical to the values used in test 4a with the exception of the following modifications:

1. The bedrock bulk saturated hydraulic conductivity of the channel nodes is set to 5 mm/day, while the bedrock for the upland nodes is made impermeable (IMBFACT = 1, IMBIBE(400) = 5 mm/day, IMBIBE(500) = 0 mm/day).

2. The soil saturated hydraulic conductivity is increased by a factor of 1000 (SKSFACT = 1000).

3. The effective flow area for surface water flow is set to 100% of the node surface area (FLAREA = 1).

Test 4C: Infiltration, Net Infiltration, and Coupled Surface Water Flow Routing

Test description: This test uses the same setup as test 4b except that the effective surface water flow area is set to 0.0001 (surface water flow affects only 0.01% of the area of each model node). These conditions allow all run-on to infiltrate at all model nodes as long as the root zone is not fully saturated, but the infiltration rate is limited because the infiltration capacity of the wetted area cannot be exceeded. The purpose of the test is to validate that the infiltration of routed surface water is dependent on the estimated wetted area of downstream cells. For these test conditions, a positive test result indicates that when runoff is generated within the watershed, outflow also occurs because the runoff cannot completely infiltrate into the channel nodes. In contrast to results for test 4b, results for test 4c should show that outflow from the watershed occurs before net infiltration has been initiated, and the duration for which routed surface water infiltrates into channel nodes is longer.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 4c. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1b.w20. All input parameters values are identical to the values used in test 4b with the exception of the following modification:

The effective surface water flow area is reduced to 0.01% of the node area (FLAREA = 0.00001).

Test 4D: Infiltration, Net Infiltration, and Coupled Surface Water Flow Routing
Test description: The setup for Test 4d consists of a specified sequence of daily precipitation amounts using a modified version of the daily climate input file mod3-ppt.dat. The modified file, Test4d.dat, has a precipitation amount of 500 mm for days 1 and 200 of each year. All remaining days have no precipitation. The soil depth and the geospatial parameter input file is the same as for test 4c, but the bedrock bulk saturated hydraulic conductivity is set to 1 mm/day for both rock types 400 and 500. The soil saturated conductivity for soil type 11 (the soil type for channel nodes) is increased by a factor of 100 (to 8467.2 mm/day). The soil saturated hydraulic conductivity for the upland nodes is left unchanged at 84.672 mm/day. The thickness of the top soil layer is reduced to 0.1 meters, thus increasing the thickness of the second soil layer to 0.9 meters. These test conditions are designed to show that the occurrence of runoff and runon are dependent on storm intensity relative to the soil saturated hydraulic conductivity. The infiltration rate during a given storm event is limited because the infiltration capacity cannot exceed the soil saturated hydraulic conductivity, even if the root zone has available storage capacity. The infiltration capacities are dependent on the estimated storm duration, where the duration of winter storms is estimated to be 12 hours and the duration of summer storms is estimated to be 2 hours. Thus, for a soil having a saturated hydraulic conductivity of 84.672 mm/day, the infiltration capacity for precipitation during a summer storm is 84.672 x (2/24) = 7.056 mm, while the infiltration capacity for precipitation during a winter storm is 84.672 x (12/24) = 42.336 mm. Summer storms are assumed to occur between day number 185 and day 274 of each year, and winter storms are assumed for all remaining days. Storm duration applies to both the duration of precipitation and the duration of surface water flow following the precipitation event. For storms resulting in the generation of runoff, the maximum daily infiltration capacity from both precipitation and surface water run-on is 2 x 7.056 = 14.112 mm for summer storms and 2 x 42.336 = 84.672 mm for winter storms for a soil having a saturated hydraulic conductivity of 84.672 mm/day.

The purpose of the test is to validate that the infiltration of routed surface water is dependent on the estimated storm duration, in conjunction with the soil saturated hydraulic conductivity. In addition, the test results should show that runoff is generated at upland nodes because the infiltration capacity of the soil layers has been exceeded. This is in contrast to conditions for test 4c in which runoff is generated at upland nodes because the root zone has become fully saturated. A positive test result should show that net infiltration at channel nodes occurs early in the simulation in response to surface water run-on, while net infiltration at upland nodes is delayed because of the lower saturated hydraulic conductivity of the soil for upland nodes. For upland nodes along the watershed divide that are not affected by surface water run-on (there are no upstream nodes), net infiltration should not occur until the final storm events in the simulation.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 4d. The daily climate input file used for this test is Test4d.dat, and the geospatial parameter input file used for this test is T1b.w20. All input parameters values are identical to the values used in test 4c with the exception of the following modifications:

1. Daily precipitation is defined using the daily precipitation amounts provided by the daily climate input file Test4d.dat (IPPTTEST = 0, PPTFILE = Test4d.dat).

2. Soil saturated hydraulic conductivity is set to 84.672 mm/day for upland nodes with soil type 10 and 8467.2 mm/day for channel nodes with soil type 11 (SKSFACT = 1, SOILKS(10) = 0.00001, SOILKS(11) = 0.001).

3. The thickness of the top soil layer is set to 0.1 meters (RDEPTH1 = 0.1).

4. The effective surface water flow area is increased to 100% of the node area (FLAREA = 1).

5. The bedrock bulk saturated hydraulic conductivity is set to 1 mm/day for both rock type 400 and rock type 500 (IMBIBE(400) = 1, IMBIBE(500) = 1).

Test 4E: Infiltration, Net Infiltration, Evapotranspiration, and Coupled Surface Water Flow Routing

Test description: This test uses a modified version of the geospatial parameter input file, T1b.w20. The modified version of the file, T1c.w20, defines a new soil and rock type for all model nodes along the watershed boundary. These nodes are within the model domain, but do not have upstream nodes, and thus do not receive surface water run-on. Using the file T1c.w20, the soil type number for upland nodes along the watershed boundary is set to 12, with a saturated hydraulic conductivity of 8467.2 mm/day defined in the model control file. The rock type number for the upland nodes along the watershed boundary is set to 450, with a bedrock bulk saturated hydraulic conductivity of 10 mm/day. The soil type number for upland nodes downstream of other upland nodes (and thus affected by surface water run-on) is set to 10, with a saturated hydraulic conductivity of 84.672 mm/day. As in test case 4d, upland nodes are defined as nodes having less then 5 upstream nodes, whereas channel nodes have 5 or more upstream nodes. The rock type number for these upland nodes with 1 to 4 upstream nodes is 500, with a bedrock bulk saturated hydraulic conductivity of 1 mm/day. The soil type number for channel nodes is 11, with a saturated hydraulic conductivity of 846.72 mm/day. The rock type number for channel nodes is 400, with a bedrock bulk saturated hydraulic conductivity of 100 mm/day. The soil depths in T1c.w20 are set to 0 for upland nodes along the watershed divide, 1 meter for downstream upland nodes, and 6 meters for channel nodes. In addition to the modified geospatial parameter inputs and corresponding soil and bedrock hydrologic properties, a constant daily evapotranspiration rate of 5 mm/day is defined using parameter options in the model control file.

For these test conditions, the infiltration of precipitation and surface water into the root zone is limited by the infiltration capacities of the soil and bedrock. Infiltration capacities are determined by the estimated storm duration, where the duration of winter storms is estimated to be 12 hours and the duration of summer storms is estimated to be 2 hours. Summer storms are assumed to occur between day number 185 and day 274 of each year, and winter storms are assumed for all remaining days. Storm duration applies to both the duration of precipitation and the duration of surface water flow following the precipitation event. During summer storms, infiltration of precipitation and surface water run-on should be limited by the lower infiltration capacity (as defined by the shorter storm duration). Thus, net infiltration in response to summer storm events should not occur until the end of the simulation period when upland nodes along the watershed divide have exceeded the water storage capacity of the rock layer, which does not contain roots and thus slowly wets up throughout the simulation. For these test conditions, evapotranspiration from soil layers is enabled, and this limits net infiltration amounts at all nodes with soil cover. The purpose of the test is to validate that the infiltration of precipitation and routed surface water is dependent on the estimated storm duration, in conjunction with watershed characteristics such as soil depth, root density, soil saturated hydraulic conductivity, and bedrock bulk saturated hydraulic conductivity. A positive test result also shows that net infiltration is dependent on the combined effects of evapotranspiration and the rate of infiltration through the root zone. In contrast to results for test 4d, results for test 4e should show that for the higher intensity summer storm events, net infiltration does not occur at model nodes with soil cover because the smaller amount of water infiltrated is removed by evapotranspiration. For upland nodes with no soil cover, evapotranspiration does not occur and thus net infiltration eventually occurs in response to infiltrated precipitation once the water content of the rock layer has reached the effective water storage capacity.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 4e. The daily climate input file used for this test is Test4d.dat, and the geospatial parameter input file used for this test is T1c.w20. All input parameters values are identical to the values used in test 4d with the exception of the following modifications:

1. Using the modified geospatial parameter input file T1c.w20, the soil thickness is set to 0 for all upland nodes along the watershed divide (nodes with no upstream nodes). Soil thickness is set to 1 meter for all upland nodes with 1 to 4 upstream nodes, and 6 meters for all channel nodes with 5 or more upstream nodes (SDFACT = 1, INFILE = T1c.w20).

2. Using the modified geospatial parameter input file T1c.w20, the soil type is set to 12 for all upland nodes along the watershed divide, 10 for all upland nodes downstream of the watershed divide, and 11 for all channel nodes (INFILE = T1c.w20).

3. Using the model control file Infilv2.ctl, the soil saturated hydraulic conductivity is set to 1E-4 Kg-sec/m^3 (84.672 mm/day) for soil type 10, 1E-3 Kg-sec/m^3 (846.72 mm/day) for soil type 11, and 1E-2 Kg-sec/m^3 (8467.2 mm/day) for soil type 12 (SKSFACT = 1, SOILKS(10) = 1E-4, SOILKS(11) = 1E-3, SOILKS(12) = 1E-2).

4. Using the modified geospatial parameter input file T1c.w20, the rock type is set to 450 for all upland nodes along the watershed divide, 500 for all upland nodes downstream of the watershed divide, and 400 for all channel nodes. (INFILE = T1c.w20).

5. Using the model control file, the bedrock bulk saturated hydraulic conductivity is set to 100 mm/day for rock type 400, 10 mm/day for rock type 450, and 1 mm/day for rock type 500 (IMBFACT = 1, IMBIBE(400) = 100, IMBIBE(450) = 10, IMBIBE(500) = 1).

6. Evapotranspiration is enabled and potential evapotranspiration is set to a constant rate of 5 mm/day (IETTEST = 1, ETFACT = 5).

7. Root density is set to 100% for the first soil layer, 50% for the second soil layer, 10% for the third soil layers, and 0% for the rock layer (ROOTF1 = 1, ROOTF2 = 0.5, ROOTF3 = 0.1, ROOTF4 = 0, MAXWGT1 = 1, MAXWGT2 = 0.5, MAXWGT3 = 0.1, MAXWGT4 = 0).

Test 4F: Infiltration, Net Infiltration, Evapotranspiration, and Coupled Surface Water Flow Routing

Test description: This test uses the same setup used for test 4e, except that the root density terms are reversed so that the maximum root density occurs at the bottom of the root zone, and evapotranspiration is disabled for the first soil layer. For these test conditions, the transpiration rate from the rock layer should prevent the water content of the layer from exceeding the effective water storage capacity at all upland nodes, preventing the occurrence of net infiltration at upland nodes. Although episodic infiltration through the overlying soil does occur in response to both summer and winter storm events, the infiltration events cannot overcome transpiration losses from the lower root zone. Net infiltration should occur at channel nodes because of the much higher run-on rates as compared to upland nodes, and because of the higher soil hydraulic conductivity relative to upland nodes affected by run-on.

The purpose of the test is to validate that the root density functions are performing as intended, and that net infiltration is dependent on parameters controlling evapotranspiration as well as other watershed characteristics such as soil depth, soil permeability, bedrock permeability, and topography. A positive test result also shows that average annual evapotranspiration, runoff, run-on, and infiltrated run-on rates are all increased relative to results for test 4e, while average annual net infiltration and the change in root zone water content rates are decreased relative to results for test 4e. The differences occur because the water content of the first soil layer is on average higher than results obtained for test 4e, while the water content of the bottom soil layer and rock layer are on average lower than results for test 4e.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 4f. The daily climate input file used for this test is Test4d.dat, and the geospatial parameter input file used for this test is T1c.w20. All input parameters values are identical to the values used in test 4e with the exception of the following modifications:

1. The root density parameters for the top soil layer are set to 0 (ROOTF1 = 0, MAXWGT1 = 0).
2. The root density parameters for the second soil layer are set to 0.1 (ROOTF2 = 0.1, MAXWGT2 = 0.1).
3. The root density parameters for the third soil layer are set to 0.5 (ROOTF3 = 0.5, MAXWGT3 = 0.5).
4. The root density parameters for the rock layer are set to 1.0 (ROOTF4 = 1.0, MAXWGT4 = 1.0).

8.2.6 Test Sequence 5: Validation of Evapotranspiration, Infiltration, Net Infiltration, and Surface Water Routing Functions in Response to the modeling of Snowfall, Snow-Melt, and Sublimation.

This test sequence consists of 4 test cases used to test the functionality of the snow-module, the interaction of the snow-module with other model components, and the interaction of the snow-module with the daily climate input parameters. The test sequence is also used to test the PET module performance in response to the simulation day-of-year number and various daily air temperature and precipitation inputs. The test criteria are based mostly on the expected response of the snow-module to daily precipitation and air temperature input, and the response of modeled ET, sublimation, and snowmelt to daily precipitation, air temperature, and day number. All test cases are evaluated by visual inspection of the two primary output files generated by INFILv2: the average daily output (daily results for all model nodes are averaged for each day of the simulation) and the average annual map file (the average annual rate for all terms of the water-balance is calculated for all model nodes).

Test 5A: Snow Cover Accumulation

Test description: This is the basic test for the snow-cover accumulation term. A positive test result indicates that precipitation occurs as snowfall and is stored as accumulated snow-cover, as long as the average daily air temperature is below freezing. For this test case, only the precipitation, snowfall, and snow-cover terms should have values greater than 0. Although sublimation is enabled, sublimation does not occur because the average daily air temperature is set to a very low value of –50 C. If the test criteria are met, this test indicates that the snow module is functioning properly because for extreme cold potential evapotranspiration = 0 and all precipitation occurs as snow, which does not sublimate or melt, and thus there is no water input to other components of the water balance.

Table A1-1 of Appendix 1 provides a complete list of all parameter values in the model control file used for this test. The test simulation is run from 1/1/1980 through 12/31/1985 using mod3-ppt.dat as the daily climate input file and t1a.w20 as the geospatial parameter input file. Using parameters in the model control file (Infilv2.ctl):

1. Precipitation input is set to a constant value of 1 mm/day (IPPTTEST = 1, PPTTEST = . 2. Daily air temperature is set to a constant value of –50 C by setting the daily air temperature model parameters (IAIRTEMP =1, ATEMP1 = -50, ATEMP2 = 0).

2. The potential evapotranspiration (PET) module is enabled by setting IETTEST = 0 and ETFACT = 1.

Test 5B: Sublimation

Test description: This is a continuation of the basic test for the snow-cover accumulation term. This test is a slightly modified version of test 5a for the purpose of testing the sublimation function. If the test criteria are met, this test indicates that the snow module and the sublimation function are performing properly because potential evapotranspiration is greater than 0, and sublimation is modeled as an empirical function of potential evapotranspiration. However, because air temperature is less than 0 degree C for all days simulated, rain or snow-melt does not occur, and thus there is no water input to other components of the water balance.

Table A1-1 of Appendix 1 provides a complete list of all parameter values in the model control file used for this test:

1. The test simulation is run from 1/1/1980 through 12/31/1985 using mod3-ppt.dat as the daily climate input file and t1a.w20 as the geospatial parameter input file.

2. Precipitation input is set to a constant value of 1 mm/day (IPPTTEST = 1, PPTTEST = 1).

3. Daily air temperature is set to a constant value of –10 C by setting the daily air temperature model parameters (IAIRTEMP =1, ATEMP1 = -10, ATEMP2 = 0).

4. The potential evapotranspiration (PET) module is enabled by setting IETTEST = 0 and ETFACT = 1.

5. The surface water routing module is de-coupled (IROUT = 0).

Test 5C: Snowfall and Snow Cover Distribution

Test description: This is a basic test of the spatial distribution of snow-fall and snow-cover terms based on the modeled air-temperature-elevation correlation, and the range of elevations included in the geospatial parameter file (t1a.w20). If the test criteria are met, this test indicates that the spatial distribution of snowfall and snow cover, which are dependent on air temperature, is correctly being modeled as a function of elevation and average air temperature on a daily basis. Because air temperature for model nodes at 1464 m and higher remain below 0 C throughout the entire simulation, only those nodes below the snow-line are affected by processes such as infiltration, evapotranspiration, net infiltration, and surface water flow.

Table A1-1 of Appendix 1 provides a complete list of all parameter values in the model control file used for this test:

1. Precipitation input is set to a constant value of 2 mm/day (IPPTTEST = 1, PPTTEST = 2).
2. Daily air temperature is set to a constant value of –0.6 C by setting the daily air temperature model parameters (IAIRTEMP =1, ATEMP1 = -0.6, ATEMP2 = 0).
3. The potential evapotranspiration module is enabled by setting IETTEST = 0 and ETFACT = 1.
4. The test simulation is run using mod3-ppt.dat as the daily climate input and t1a.w20 as the geospatial parameter input. The test simulation is run from 1/1/1980 through 12/31/1985.

Test 5D: Spatial and Temporal Distribution of Snowfall and Snow Cover
Test description: This is a basic test of the combined spatial and temporal distribution of snowfall and snow cover terms based on the modeled air-temperature-elevation correlation, and the range of elevations included in the geospatial parameter file (t1a.w20). If the test criteria are met, this test indicates that the combined spatial and temporal distribution of snowfall and snow cover, which are dependent on air temperature, is correctly being modeled as a function of elevation and day of year number. A positive test result indicates that the processes of snow pack development during winter when air temperatures are below freezing and snowmelt during spring as air temperature increases with a subsequent increase in evapotranspiration are being modeled correctly. The spring snowmelt causes a large increase in runoff following the saturation of the root-zone. This is followed by diminished runoff during the summer after the snow pack has melted. The cycle is repeated for each year of the simulation.

Table A1-1 of Appendix 1 provides a complete list of all parameter values in the model control file used for this test. The following list indicates the critical changes made to the model control file:

1. Precipitation input is set to a constant value of 2 mm/day (IPPTTEST = 1, PPTTEST = 2).
2. Daily air temperature is set to an average annual value of –0.6 C with a summer maximum of +19.4 C and a winter minimum of -20.6 C by setting the daily air temperature model parameters (IAIRTEMP =1, ATEMP1 = -0.6, ATEMP2 = 20).
3. The potential evapotranspiration module is enabled by setting IETTEST = 0 and ETFACT = 1.
4. The soil saturated hydraulic conductivity for soil type 10 is set to 1E-3 Kg sec/m^3 (SOILKS(10) = 1E-3).
5. The bedrock bulk saturated hydraulic conductivity is set to 1 mm/day (IMBIBE(500) = 1).
6. The test simulation is run using mod3-ppt.dat as the daily climate input and t1a.w20 as the geospatial parameter input. The test simulation is run from 1/1/1980 through 12/31/1985.

9. CONCLUSION

The no-error (successful) results of the USGS-YMPB execution of the installation test are presented in Appendix 2, Table A2-1. The test run meets the specified criteria indicated in the ITP and the test case output files are consistent with those criteria specified.

Results of the software program functionality validation test described in the USGS-YMPB validation test plan are included as Appendix 2, Table A2-2. As noted elsewhere, a checkmark entered by the validation tester is the indication that the results were checked and found to satisfy the acceptance criteria that all conditions as stated were met. These results confirm successful validation of INFIL V2.0.

To conclude, the test results are found to satisfy the acceptance criteria described in the Validation Test Plan for INFIL V2.0, and meet each of the test sequence requirements listed in Appendix 2 and described in the RD and DD. Correct installation and indication that the software is performing (functioning) as designed further is validated by the successful run of the Installation/Functionality tests. There are no identified remaining test exceptions or failures. In accordance with AP-SI.1Q, section 5.9.3.1, appropriate software validation has been performed to meet the requirements of Section 5.6.

10. DOCUMENTS CITED

Altman, S.J.; Arnold, B.W.; Barnard, R.W.; Barr, G.E.; Ho, C.K.; McKenna, S.A.; and Eaton, R.R. 1996. *Flow Calculations for Yucca Mountain Groundwater Travel Time (GWTT-95).* SAND96-0819. Albuquerque, New Mexico: Sandia National Laboratories. ACC: MOL.19961209.0152.

Buesch, D.C.; Spengler, R.W.; Moyer, T.C.; and Geslin, J.K. 1996. *Proposed Stratigraphic Nomenclature and Macroscopic Identification of Lithostratigraphic Units of the Paintbrush Group Exposed at Yucca Mountain, Nevada.* Open-File Report 94-469. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19970205.0061.

Campbell, G.S. 1977. *An Introduction to Environmental Biophysics.* New York, New York: Springer-Verlag. TIC: 238256.

Campbell, G.S. 1985. *Soil Physics with BASIC Transport Models for Soil-Plant Systems.* Developments in Soil Science 14. Amsterdam, The Netherlands: Elsevier Science B.V. TIC: 214477.

CRWMS M&O 2000a. *Unsaturated Zone Flow and Transport Model Process Model Report.* TDR-NBS-HS-000002 REV 00 ICN 02. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000831.0280. ← 09/26/01

CRWMS M&O 2000b. *Analysis of Infiltration Uncertainty.* ANL-NBS-HS-000027 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000525.0377.

CRWMS M&O 2000c. *Analysis of Geochemical Data for the Unsaturated Zone.* ANL-NBS-HS-000017 rev 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20010405.0013

CRWMS M&O 2000d. *Geochemical and Isotopic Constraints on Ground-Water Flow Directions, Mixing, and Recharge at Yucca Mountain, Nevada.* ANL-NBS-HS-000021 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20010123.0120

CRWMS M&O 2000e. *Technical Work Plan for Unsaturated Zone (UZ) Flow and Transport Process Model Report.* TWP-NBS-HS-000001, Rev 01. Las Vegas, Nevada; CRWMS M&O. ACC: MOL.20010404.007

Davies, J.A. and Allen, C.D. 1993. *Equilibrium, potential, and actual evaporation from cropped surfaces in southern Ontario.* Journal of Applied Meteorology, Vol 12, p. 649-657.

Day, W.C.; Potter, C.J.; Sweetkind, D.S.; Dickerson, R.P.; and San Juan, C.A. 1998. *Bedrock Geologic Map of the Central Block Area, Yucca Mountain, Nye County, Nevada.* Map I-2601. Washington, D.C.: U.S. Geological Survey. TIC: 237019.

deBruin, H.A.R. 1988. *Evaporation in arid and semi-arid regions, in,* "Estimation of natural groundwater recharge", ed., Simmers, I., Reidel Publishing Company, Boston, MA., p. 73-88.

Eichinger, W.E.; Parlange, M.B.; and Stricker, H. 1996. "On the Concept of Equilibrium Evaporation and the Value of the Priestley-Taylor Coefficient." *Water Resources Research, 32,* (1), 161-164. Washington, D.C.: American Geophysical Union. TIC: 245924.

Flint, A.L. and Childs, S.W. 1984. "Physical Properties of Rock Fragments and Their Effect on Available Water in Skeletal Soils." Chapter 10 of *Erosion and Productivity of Soils Containing Rock Fragments.* SSSA Special Publication #13. Madison, Wisconsin: Soil Science Society of America. TIC: 247223.

Flint, A.L. and Childs, S.W. 1987. "Calculation of Solar Radiation in Mountainous Terrain." *Agricultural and Forest Meteorology, 40,* (3), 233-249. Amsterdam, The Netherlands: Elsevier Science Publishers B.V. TIC: 225242.

Flint, A.L. and Childs, S.W. 1991. "Use of the Priestley-Taylor Evaporation Equation for Soil Water Limited Conditions in a Small Forest Clearcut." *Agricultural and Forest Meteorology, 56,* (3-4), 247-260. Amsterdam, The Netherlands: Elsevier. TIC: 241865.

Flint, A.L.; Hevesi, J.A.; and Flint, L.E. 1996. *Conceptual and Numerical Model of Infiltration for the Yucca Mountain Area, Nevada.* Milestone 3GUI623M. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19970409.0087.

Flint, L.E. 1998. *Characterization of Hydrogeologic Units Using Matrix Properties, Yucca Mountain, Nevada.* Water-Resources Investigations Report 97-4243. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19980429.0512.

Flint, L.E. and Flint, A.L. 1995. *Shallow Infiltration Processes at Yucca Mountain, Nevada—Neutron Logging Data 1984-93.* Water-Resources Investigations Report 95-4035. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19960924.0577.

Freeze, R.A. and Cherry, J.A. 1979. *Groundwater.* Englewood Cliffs, New Jersey: Prentice-Hall. TIC: 217571.

French, R.H. 1983. "Precipitation in Southern Nevada." *Journal of Hydraulic Engineering, 109,* (7), 1023-1036. New York, New York: American Society of Civil Engineers. TIC: 238300.

Hatton, T. 1998. *Catchment Scale Recharge Modelling.* Part 4 of The Basics of Recharge and Discharge. Zhang, L., ed. Collingwood, Victoria, Australia: CSIRO Publishing. TIC: 247711.

Hevesi, J.A. and Flint, A.L. 1998. "Geostatistical Estimates of Future Recharge for the Death Valley Region." *High-Level Radioactive Waste Management, Proceedings of the Eighth International Conference, Las Vegas, Nevada, May 11-14, 1998.* Pages 173-177. La Grange Park, Illinois: American Nuclear Society. TIC: 237082.

Hevesi, J.A.; Ambos, D.S.; and Flint, A.L. 1994a. "A Preliminary Characterization of the Spatial Variability of Precipitation at Yucca Mountain, Nevada." *High-Level Radioactive Waste Management, Proceedings of the Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994. 4,* 2520-2529. La Grange Park, Illinois: American Nuclear Society. TIC: 210984.

Hevesi, J.A.; Flint, A.L.; and Flint, L.E. 1994b. "Verification of a One-Dimensional Model for Predicting Shallow Infiltration at Yucca Mountain." *High Level Radioactive Waste Management, Proceedings of the Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994. 4,* 2323-2332. La Grange Park, Illinois: American Nuclear Society. TIC: 210984.

Hevesi, J.A.; Flint, A.L.; and Istok, J.D. 1992. "Precipitation Estimation in Mountainous Terrain Using Multivariate Geostatistics. Part II: Isohyetal Maps." *Journal of Applied Meteorology, 31,* (7), 677-688. Boston, Massachusetts: American Meteorological Society. TIC: 225248.

Jury, W.A.; Gardner, W.R.; and Gardner, W.H. 1991. *Soil Physics.* 5th Edition. New York, New York: John Wiley & Sons. TIC: 241000.

Kwicklis, E.M.; Thamir, F.; Healy, R.W.; and Hampson, D. 1998. *Numerical Simulation of Air- and Water-Flow Experiments in a Block of Variably Saturated, Fractured Tuff from Yucca Mountain, Nevada.* Water-Resources Investigations Report 97-4274. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19981215.0103.

Liu, H.H.; Doughty, C.; and Bodvarsson, G.S. 1998. "An Active Fracture Model for Unsaturated Flow and Transport in Fractured Rocks." *Water Resources Research, 34,* (10), 2633-2646. Washington, D.C.: American Geophysical Union. TIC: 243012.

Maidment, D.R., ed. 1993. *Handbook of Hydrology.* New York, New York: McGraw-Hill. TIC: 236568.

McNaughton, K.G. and Spriggs, T.W. 1989. "An Evaluation of the Priestley and Taylor Equation and the Complementary Relationship Using Results from a Mixed-Layer Model of the Convective Boundary Layer." *Estimation of Areal Evapotranspiration, Proceedings of an International Workshop Held During the XIXth General Assembly of the International Union of Geodesy and Geophysics at Vancouver, British Columbia, Canada, 9-22 August, 1987. 177,* 89-104. Wallingford, United Kingdom: International Association of Hydrological Sciences. TIC: 245925.

Nichols, W.D. 1987. *Geohydrology of the Unsaturated Zone at the Burial Site for Low-Level Radioactive Waste Near Beatty, Nye County, Nevada.* Water-Supply Paper 2312. Denver, Colorado: U.S. Geological Survey. ACC: NNA.19920428.0023.

Priestley, C.H.B. and Taylor, R.J. 1972. "On the Assessment of Surface Heat Flux and Evaporation Using Large-Scale Parameters." *Monthly Weather Review, 100,* (2), 81-92. Washington, DC: U.S. Department of Commerce. TIC: 235941.

Savard, C.S. 1995. *Selected Hydrologic Data from Fortymile Wash in the Yucca Mountain Area, Nevada, Water Year 1992.* Open-File Report 94-317. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19941208.0002.

Sawyer, D.A.; Wahl, R.R.; Cole, J.C.; Minor, S.A.; Laczniak, R.J.; Warren, R.G.; Engle, C.M.; and Vega, R.G. 1995. *Preliminary Digital Geological Map Database of the Nevada Test Site Area, Nevada.* Open-File Report 95-0567. Denver, Colorado: U.S. Geological Survey. TIC: 232986.

Scott, R.B. and Bonk, J. 1984. *Preliminary Geologic Map of Yucca Mountain, Nye County, Nevada, with Geologic Sections.* Open-File Report 84-494. Denver, Colorado: U.S. Geological Survey. TIC: 203162.

Stannard, D.I 1993. *Comparison of Penman-Monteith Shuttleworth-Wallance and modified Priestley-Taylor evapotranspiration models for wildland vegetation in semiarid rangeland.* Water Resources Research, 29 (5), p. 1379-1392. American Geophysical Union. Washington, DC.

Stewart, R.B. and Rouse, W.R. 1977. "Substantiation of the Priestley and Taylor Parameter [alpha]=1.26 for Potential Evaporation in High Latitudes." *Journal of Applied Meteorology, 16,* 649-650. [Boston, Massachusetts: American Meteorological Society]. TIC: 245923.

Thompson, R.S.; Anderson, K.H.; and Bartlein, P.J. 1999. *Quantitative Paleoclimatic Reconstructions from Late Pleistocene Plant Macrofossils of the Yucca Mountain Region.* Open-File Report 99-338. Denver, Colorado: U.S. Geological Survey. TIC: 245688.

USGS 1996. *Software Code: MARKOV.* V1.0. 10142-1.0-00.

USGS (U.S. Geological Survey) 2000a. *Simulation of Net Infiltration for Modern and Potential Future Climates AMR.* Development Plan TDP-NBS-HS-000016 REV 01. [Denver, Colorado]: U.S. Geological Survey. ACC: MOL.20000516.0011.

USGS (U.S. Geological Survey) 2000b. *Future Climate Analysis.* ANL-NBS-GS-000008 REV 00. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20000629.0907.

USGS (U.S. Geological Survey) 2001. *Simulation of Net Infiltration for Modern and Potential Future Climates.* ANL-NBS-HS-000032 REV 00 ICN 01. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20010405.0002.

APPENDIX 1

APPENDIX 1-A: INFIL V2.0 MODEL CONTROL FILE

A. Model Control File Variable Order

```
read(7,5) header
read(7,*) optmassb
read(7,*) irout, ifrtol
read(7,*) isnow,isnwmod,snopar1
read(7,*) isublim,subpar1,subpar2
read(7,*) ippttest,ppttest
read(7,*) iettest,ettest
read(7,*) celsize
read(7,*) xcfs,ycfs
read(7,*) yrbeg,dnbeg,yrend,dnend,tyear1,tyear2
read(7,*) pptfact,etfact,imbfact,sksfact
read(7,*) sdfact,ivegc,fvegc
read(7,*) rootf1,rootf2,rootf3,rootf4
read(7,*) maxwgt1,maxwgt2,maxwgt3,maxwgt4
read(7,*) rdepth1,rdepth2,rdepth4,rdepthf
read(7,*) rkpor,rkmmfact,flarea
read(7,*) infmod,etmod,runmod
read(7,*) barsoil1,barsoil2
read(7,*) iairtemp,atemp1,atemp2
read(7,*) hstep
read(7,*) pptyuc,aaprepx,ipptdat
read(7,5) pptfile
read(7,*) depthflg,irtz,delvwcf,moistcr,fracmod
read(7,*) ivwcflg,vwcfact
read(7,5) vwcfile
read(7,5) infile
read(7,*) locstart
read(7,5) Dayall
read(7,*) ndaymap, imap
read(7,*) irday(i),nyrout(i)
read(7,5) daymap(i)
read(7,5) outfile
read(7,5) flxfile
read(7,*) dbgflag,dbgflag2
read(7,5) dbgfile
read(7,*) idebug
read(7,5) dbugout
read(7,*) outyear1
read(7,5) header0
read(7,*) numdepth
```

```
read(7,*) idpth,idpth2,rtza(idpth),rtzb(idpth),
   1        rtzc(idpth),rtzd(idpth),bsoil(idpth),
   2        vwcf2(idpth)
      read(7,5) dumbhead
    read(7,*) nsoilid
      read(7,*) soilid,fieldcap(soilid),soilresid(soilid),
   1          soilporo(soilid),soilalbeta(soilid),
   2          soiltalpha(soilid),soilks(soilid),soilpe(soilid),
   3          soilbval(soilid),salpha(soilid),soilvgn(soilid),
   4          sorp(soilid),soilpond(soilid),potis(soilid)
      read(7,5) dumbhead
    read(7,*) nrockid
      read(7,*) rockid,rockcap(rockid),rockresid(rockid),
  1                   rockporo(rockid),rockalbeta(rockid),
  2        rocktalpha(rockid),rockks(rockid),rockpe(rockid),
  3        rockbval(rockid),ralpha(rockid),rockvgn(rockid),
  4        rockfracks(rockid),imbibe(rockid),potir(rockid)
```

B. Model Control File Input Variables.

Control FileInput Parameter	DESCRIPTION	FORMAT
HEADER	Model run identification: date, input file names, etc.	A (character data)
OPTMASSB	0 to stop runoff routing on last day of simulation	* (list-directed I/O)
IROUT	0 for de-coupled flow routing; 1 for coupled routing;-1 for no flow routing; -2 for no infiltration	*
IFRTOL	Flow routing tolerance term	*
ISNOW	Internal testing options (validation)0 : snow module dissabled; 2 : snow module enabled	*
ISNWMOD	isnwmod = I : snow-cover model type= 1 for setting et = 0 for days at freezing or below= 2 for snow-cover module enabled	*
SNOPAR1	snopar1 = model parameter	*
ISUBLIM	isublim = sublimation model option (0 = off, 1 = on)	*
SUBPAR1	subpar1 = sublimation factor if air temperature less than or equal to 0.	*
SUBPAR2	subpar2 = sublimation factor if air temperature greater than 0	*
IPPTTEST	Internal testing options (validation): ippttest = 1 (for testing)sets precip to constant = ppttest. ippttest = 0 for modeling	*
PPTTEST	Constant precip value for testing	*
IETTEST	Internal testing options (validation): = 1 (for testing) sets et to constant = ettest. Iettest = 0 for modeling	*
ETTEST	Constant et value for testing.	*
CELSIZE	celsize from control file to calculate discharge. Size hard-wired for 30-meter grid.	*
XCFS	X coordinate for generating discharge (cfs) at user specified location (cell)	*
YCFS	Y coordinate for generating discharge (cfs) at user specified location (cell)	*
YRBEG	Simulation starting year. For using measured daily precipitation as input (described below). Gregorian calendar year.	*

Control FileInput Parameter	DESCRIPTION	FORMAT
DNBEG	Integer, (0 ≤ dnn1 ≤ 366). Simulation starting day number (example; 1= January 1, 365 = December 31 for non-leap year). If precipitation input file begins prior to the date represented by the starting year and starting day, this part of the input file will be ignored by the program INFIL. Julian day number.	*
YREND	Simulation ending year. For using measured daily precipitation as input (described below). Gregorian calendar year.	*
DNEND	Integer, (0 ≤ dn2 ≤ 366). Simulation ending day number (example; 1 - January 1, 365 - December 31 for non-leap year). If precipitation input file ends after the date represented by ending year and ending day, this part of the input file will be ignored by the program INFIL.	*
TYEAR1	Determines type of simulation output. Domain of values is 0 or 1. = 0 for straight annual totals. =1 for annual avg. for multi-years	*
TYEAR2	Interval (in years) for calculating multi-year averages from above.	*
PPTFACT	PPTFACT, real, (0 ≤ pptfact). Scaler for increasing or decreasing the magnitude of daily precipitation. Values greater than 1.0 increase precipitation, values less than 1 decrease precipitation.	*
ETFACT	ETFACT, real (0 ≤ etfact). Scaler for increasing or decreasing the magnitude of daily potential evapotranspiration. Values greater than 1.0 increase precipitation, values less than 1 decrease precipitation.	*
IMBFACT	Bedrock permeability (mm/day) scaling factor	*
SKSFACT	Soil permeability scaling factor	*
SDFACT	Soil depth scaling factor	*
IVEGC	Used to invoke vegetation map cover in et calculation when IVEGC = 1	*
FVEGC	constant vegetation cover factor used in et calculation when IVEGC = 0	*
ROOTF1	Upper cascading bucket evapotranspiration weighting function limit	*
ROOTF2	Second cascading bucket evapotranspiration weighting function limit	*
ROOTF3	Third cascading bucket evapotranspiration weighting function limit	*
ROOTF4	Lower cascading bucket evapotranspiration weighting function limit	*
MAXWGT1	Dynamic root zone weighting function for simulation evapotransipiration for layer 1	*
MAXWGT2	Dynamic root zone weighting function for simulation evapotransipiration for layer 2	*
MAXWGT3	Dynamic root zone weighting function for simulation evapotransipiration for layer 3	*
MAXWGT4	Dynamic root zone weighting function for simulation evapotransipiration for layer 4	*
RDEPTH1	Root zone depth 1: Index variable for associating root-zone parameters to soil depth class IDPTH. Values for IDPTH must correspond to depth classes as identified in the location parameter input file.	*
RDEPTH2	Root zone depth 2	*
RDEPTH4	Root zone depth 3	*
RDEPTHF	Estimated root zone depth	*
RKPOR	Rock porosity, id est effective bedrock storage capacity variable	*
RKMMFACT	Initial rock water content condition	*
FLAREA	Effective surface-water flow area	*
INFMOD	Infiltration module. = 1 for slow drainage function, =2 for full darinage.	*
ETMOD	Evapotranspiration module. = 1 if module is on.	*

Control FileInput Parameter	DESCRIPTION	FORMAT
RUNMOD	Run-off routing module. =2,3 to allow slow, of full net infiltration when effective bedrock storage capacity > 0. = 1 to allow simple net infiltration only when effective bedrock storage capacity is exceeded. = 0 allows net infiltration to occur only during infiltration module calculations.	*
BARSOIL1	Bare soil et parameter	*
BARSOIL2	Bare soil et parameter	*
IAIRTEMP	Air temperature model. Domain of values –1, 1, 2, 3, other	*
ATEMP1	ATEMP1 = avg. air temp (deg. C)	*
ATEMP2	ATEMP2 = half amplitude of air temp (seasonal) deviation (deg. C)	*
HSTEP	HSTEP, real, hours (1 ≤ hstep ≤ 4). Time step used in POTEVAP subroutine for simulating potential evapotranspiration using a solar radiation model and an energy balance method. Values of either 1 or 2 are recommended	*
PPTYUC	PPTYUC, integer, (0 ≤ pptyuc ≤ 5). Option for using a function to account for the spatial variability of daily precipitation over Yucca Mountain.pptyuc = 5 for monsoon climatepptyuc = 4 for future climatespptyuc = 3 for Yucca Mt (4JA) using constant scalerpptyuc = 2 for Yucca Mt (4JA) using variable scalerpptyuc= 1 for analog climate simulations (Area 12, etc)pptyuc = (0) for uniform precip distributionvalues used for original 1996 precip model - -3, -2, -1	*
AAPREPX	Average annual precip for site. Use when PPTYUC = 5	*
IPPTDAT	ipptdat = input data type:IPPTDAT = 0 for daily precip data from a single site.IPPTDAT = 1 for simulated precip input from PPTSIM.IPPTDAT = 3 for reading output generated by DAILY09	*
PPTFILE	pptfile (unit 11) = daily precip input file	A
DEPTHFLG	Integer, (0 1). Option used for specifying the root-zone sub-model to be used for simulating evapotranspiration. IRTZ is set to 1 for using a dynamic root-zone sub-model which calculates root-zone weighting factors as a function of root-zone depth and water contect. IRTZ is set to 0 for using a static root-zone sub-model which calculates root-sub-model, evapotranspiration is simulated as a function of potential evapotranspiration, water content, and the root-zone weighting factors. Root-zone weighting factors are not used when the bucket sub-model is used. Unused.	*
IRTZ	Set to 1 for using a dynamic root-zone sub-model which calculates root-zone weighting factors as a function of root-zone depth and water contect. IRTZ is set to 0 for using a static root-zone sub-model which calculates root-sub-model, evapotranspiration is simulated as a function of potential evapotranspiration, water content, and the root-zone weighting factors Unused.	*
DELVWCF	*Not used:* Real, (0< delvwcf). Exponent used in the dynamic root-zone sub-model for controlling the relative effect of changes in water content on root-zone weighting factors. Values less than 1 are used for decreasing the relative effect of water contents, values greater than 1 are used for increasing the relative effect	*
MOISTCR	Integer, (0, 1). Option for selecting the moisture characteristic functions to be used in the Richards equation sub-model. Set to 1 for using a Brooks and Corey type moisture characteristic, 0 for using a van Genuchten type moisture characteristic. The van Genuchten version is not fully functional with the current version of INFIL. This parameter serves only as a place-holder until later versions of INFIL are completed Unused.	*

Control FileInput Parameter	DESCRIPTION	FORMAT
FRACMOD	integer, (0, 1). Option for setting the fracture flow sub-model to be used in the Richards equation sub-model. Set to 1 for using a storage type fracture sub-model which simulates imbibition of fracture flow back into the bedrock matrix. Set to 0 for using a simplified approach which assumes all fracture flow in bedrock becomes net infiltration Unused.	*
IVWCFLG	fromc previous simulation as initial conditions forc next simulationSet = 0 for model simulations	*
VWCFACT	Initial vwc determined by residual VWC and vwcfactsoilvwc(ia) = soilresid(soiltype(ia))*vwcfactif((ivwcflg.eq.1).and.(locid(ia).eq.locid2))buckvwc, initvwc,finalvwc Unused when VWCFACT = 0	*
INFILE	main input file: geospatial input parameters	A
LOCSTART	Not used. (4/30/97 to allow re-start in case of power loss) Set to -1	*
DAYALL	File name variable for daily mass balance terms averaged for all points output.	A
NDAYMAP	Number of 24-hour mass balance results for mapping.maximum of 10 output files	*
IMAP	I = 1 to 10 for number of an individual DAYMAP output file.	*
IRDAY	The number of days for a DAYMAP output	*
NYROUT	The year for the 24-hour mass balance map results	*
DAYMAP	File name for 24-hour mass balance results for mapping output	A
OUTFILE	File name for summary information and annual summary statistics output	A
FLXFILE	File name for average annual mass balance terms output	A
DBGFLAG	Integer, ($1 \leq$ dbgflag ≤ 9). Option for control of output to main output file. Set to 1 for standard simulation results consisting of daily mass balance terms for a specified location. Set to 9 for generating average mass balance terms calculated for all locations. Values in between 1 and 9 are used for testing and debugging purposes	*
DBGFLAG2	Integer, (0, 1) option for generating total yearly mass balance results	*
DBGFILE	File name for 2nd daily mass balance output file	A
IDEBUG	Integer, (-1 < idebug < 3)To check mass balance (if = 0, echo input parameters)	*
DBUGOUT	File name for output file to hold debugging list of inputs. If idebug does not = 0 then write dbugout	A
OUTYEAR1	File name (prefix) for output map – annual totals or multi-year averages	*
HEADER0	Root zone parameter names	A
NUMDEPTH	Number of root-zone parameter lines in control file. Counter.	*
IDPTH	Root-zone parameter line index number	*
IDPTH2	real, meters, (0 < IDPTH2 $\leq$ 100)	*
RTZA	(idpth), real, (0 < rtza). Estimated or fitted parameter for function defining root density as a function of depth.	*
RTZB	(idpth), real, (0 < rtzb). Estimated or fitted parameter for function defining root density as a function of depth.	*
RTZC	(idpth), real, (0 < rtzc). Estimated or fitted parameter for function defining root density as a function of depth.	*
RTZD	(idpth), real, (0 < rtzd). Estimated or fitted parameter for function defining root density as a function of depth	*
BSOIL	(idpth), real (0 < rtzb). Estimated or fitted parameter for controlling the relative proportion of total evapotranspiration occurring as bare soil evaporation from the top element of the finite difference mesh.	*

Control FileInput Parameter	DESCRIPTION	FORMAT
VWCF2	(IDPTH), real, (0 < vwcf2). Estimated or fitted parameter for function used to condition the dynamic root-zone weighting function so as to decrease the effect of high water contents with increasing depth.	*
DUMBHEAD	Soil property parameter names	A
NSOILID	Number of soil-property parameter lines in control file. Counter.Integer, (1 ≤ nosoilid ≤ 20). Total number of soil types to be used in mass balance calculations for either the Richards equation or the bucket sub-models. This line must be followed by nsoilid lines consisting of parameters for each soil type. All parameters in line 30 must be repeated nsoilid times. The current version of INFIL is dimensioned to allow a maximum of 20 different soil types.	*
SOILID	Soil-property parameter line index number.	*
FIELDCAP	The water content of the near surface soil profile (i.e., the root zone) at which drainage becomes negligible	*
SOILRESID	(soilid), Estimated or measured residual water content for evapotranspiration. Approximately equivalent to the wilting point, but can be set lower as a means of indirectly accounting for vapor flow contributions to evapotranspiration	*
SOILPORO	(soilid), Soil porosity (or effective fracture porosity in the case of bedrock).), Real m^3/m^3, (fieldcap ≤ fieldcap). Estimated or measured soil porosity. Values are seldom less than 0.15 and higher than 0.70 for most field conditions	*
SOILALBETA	(soilid), Real (soilalbeta ≤ 0). Estimated or fitted parameter for defining evapotranspiration as a function of soil water content and potential evapotranspirtation using the modified Priestley-Taylor equation. Increasing the absolute magnitude of soilalbeta increases evapotranspiration for a given water content. Values ranging from 10.0 to -1.5 are recommended for modeling field conditions	*
SOILTALPHA	(soilid), Real, (0 ≤ soiltalpha). Estimated or fitted parameter for defining evapotranspiration as a function of soil water content and potential evapotranspiration using the modified Priestley-Taylor equation. The value of soiltalpha may increase evapotranspiration for a given water content, depending on the value of soilalbeta. Values ranging from 0.60 to 1.26 are recommended for this parameter for modeling most field conditions	*
SOILKS	(soilid), real, J-sec/m^3, (0 ≤ soilks). Estimated or measured hydraulic conductiviity. This parameter is used only in the Richards equation sub-model in the current version of INFIL	*
SOILE	(soilid), real, J/Kg, (soilpe ≤ 0). Estimated or measured air-entry water potential. This parameter is used in the Brooks and Corey type moisture characteristic functions	*
SOILBVAL	(soilid), real, (0 ≤ soilbval). Estimated or fitted shape parameter for defining the shape of the Brooks and Corey type moisture characteristic function	*
SALPHA	(soilid), 1/(J/Kg), (0 ≤ salpha). Estimated or fitted parameter defining the van Genuchten type moisture characteristic function used in the Richards equation sub-model. This parameter serves only as a place holder, and is not used by the current version of the program INFIL	*
SOILVGN	(soilid), real, (0 ≤ soilvgn). Estimated or fitted parameter defining the van Genuchten type moisture characteristic function used in the Richards equation sub-model. This parameter serves only as a place holder, and is not used by the current version of the program INFIL	*
SORP	(soilid), real, J·sec/ m^3,(0≤ sorp). Estimated or fitted measured sorptivity value for soil type. This parameter serves only as a place holder, and is not used by the current version of the program INFIL	*

Control FileInput Parameter	DESCRIPTION	FORMAT
SOILPOND	(soilid), real, m^3/m^3, (0 ≤ soilpond ≤ soilporo). Estimated or measured parameter used in the Richards equation sub-model for defining the soil water content at which water is stored as excess precipitation and is used as potential runoff in the water balance. Porosity minus the soilpond term determines the water content at which additional moisture is considered excess and is transferred to overlying elements. If excess water is produced in the top element, this water is accumulated in the runoff term of the water balance	*
POTIS	Estimated or measured water potential which is used to define initial conditions	*
DUMBHEAD	Rock-property parameter names.	A
NROCKID	Number of rock-property lines in control file. Counter.Integer, (0≤ rockid ≤ 300). Rock type identification number for referencing rock properties data to location parameters specified in the INPUT file. The current version of INFIL allows for a maximum of 300 different rock types. Rockid numbers need not be sequential for the nrockid number of lines.	*
ROCKID	Rock-property parameter line index number.	*
ROCKCAP	(rockid), real, m^3/m^3 ,(rockresid ≤ rockcap ≤ rockporo). Estimated or measured field capacity term for rock types specified by rockid. This parameter is used only by the Richards equation sub-model for modeling the occurrence of fracture flow.	*
ROCKRESID	(rockid), real m^3/m^3, (0 ≤ rockresid ≤ rockcap). Estimated or measured residual water content for evapotranspiration. Approximately equivalent to the wilting point for plants having roots extending into open bedrock fractures, but can be set lower as a means of indirectly accounting for vapor flow contributions to evapotranspiration. This parameter is used only by the Richards equation sub-model.	*
ROCKPORO	(rockid), real, m^3/m^3, (rockcap ≤ rockporo ≤ 1). Estimated or measured rock porosity. Values are seldom less than 0.01 and higher 0.50 for most field conditions. This parameter is used by only by the Richards equation sub-model.	*
ROCKALBETA	(rockid), real, (rockalbeta ≤ 0). Estimated or fitted parameter used in the modified Priestley-Taylor equation for defining evapotranspiration as a function of rock-matrix water content and potential evapotranspiration. Increasing the absolute magnitude of rockalbeta increases evapotranspiration for a given water content. Although values ranging from -10.0 to -1.5 are recommended for a modeling field conditions for soils, values for rock materials are less certain at this time. This parameter is used only by the Richards equation sub-model.	*
ROCKTALPHA	(rockid), real, (0 ≤ rocktalpha). Esitmated or fitted parameter used in the modified Priestley-Taylor equation for defining evapotranspiration as a function of rock-matrix water content and potential evapotranspiration. The value of rocktalpha determines the upper limit of evapotranspiration as a function of water content and potential evapotranspiration. Increasing the absolute magnitude of rocktalpha may increases evapotranspiration for a given water content, depending on the value of rockalbeta. Values ranging from 0.60 to -1.26 are recommended for this parameter for modeling most field conditions.	*
ROCKKS	(rockid), real, J·sec/m^3, (0 ≤ rockks). Estimated or measured hydraulic conductivity for bedrock matrix. This parameter is used only in the Richards equation sub-model in the current version of INFIL.	*
ROCKPE	ROCKPE(rockid), real, J/Kg, (rockpe ≤ 0). Estimated or measured air-entry water potential for bedrock matrix. This parameter is used in the Brooks and Corey type moisture characteristic functions of the Richards equation sub-model.	*

Control FileInput Parameter	DESCRIPTION	FORMAT
ROCKBVAL	(rockid), real, (0 ≤ rockbval). Estimated or fitted shape parameter for defining the shape of the Brooks and Corey type moisture characteristic function used in the Richards equation sub-model.	*
RALPHA	(rockid), real, 1(J/Kg), (0 ≤ ralpha). Estimated or fitted parameter defining the van Genuchten type moisture characteristic function used in the Richards equation sub-model.	*
ROCKVGN	(rockid), real, (0 ≤ rockvgn). Estimated or fitted parameter defining the van Genuchten type moisture characteristic function used in the Richards equation sub-model.	*
ROCKFRACKS	(rockid), real, J·sec/m^3, (0 ≤ rockfracks). Estimated or measured parameter used for defining the specified fracture flux as a sink term in the Richards equation sub-model. The specified flux is applied in the governing flow equation if water content becomes greater than rockcap(rockid).	*
IMBIBE	N/A ((rockid), real, mm/day, (0≤ imbibe). Estimated or measured parameter representing the field-scale or bulk (matrix plus fractures) saturated hydraulic conductivity of the bedrock material. Used only by the Bucket sub-model as a potential net infiltration term in the mass balance calculation)	
POTIR	(rockid), real, J/Kg, (potis ≤ 0). Estimated or measured water potential which is used to define initial conditions for bedrock for simulations using the Richards equation sub-model.	*

Table A1-1. Input for test cases: control file parameter values

Control File Input Parameter	Test Case						
	0A	0B	0C	0D1	0D2	0D3	1A
OPTMASSB	1	1	1	1	1	1	1
IROUT	0	1	1	1	1	1	0
IFRTOL	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08
ISNOW	2	2	2	2	2	2	2
ISNWDOW	2	2	2	2	2	2	2
SNOWPAR1	1.78	1.78	1.78	1.78	1.78	1.78	1.78
ISUBLIM	3	3	3	3	3	3	3
SUBPAR1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SUBPAR2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
IPPTTEST	0	0	0	0	0	0	0
PPTTEST	1	1	1	1	1	1	1
IETTEST	0	0	0	0	0	0	0
ETTEST	0	0	0	0	0	0	0
CELSIZE	30	30	30	30	30	30	30
XCFS	544691	547931	547931	547931	547931	547931	544691
YCFS	4074153	4077483	4077483	4077483	4077483	4077483	4074153
YRBEG	1980	1	1951	1980	1980	1980	1980
DNBEG	1	1	1	1	1	1	1
YREND	1995	100	1997	1985	1985	1985	1995
DNEND	274	365	365	365	365	365	274
TYEAR1	0	1	1	1	1	1	0
TYEAR2	1	10	5	5	5	5	1
PPTFACT	0	1	1	1	1	1	0
ETFACT	0	1	1	1	1	1	0
IMBFACT	0	1	1	1	1	1	0
SKSFACT	0	1	1	1	1	1	0
SDFACT	0	1	1	1	1	1	0
IVEGC	0	0	0	0	0	0	0
FVEGC	0.2	0.2	0.6	0.6	0.6	0.6	0.2

Control File Input Parameter	Test Case						
	0A	0B	0C	0D1	0D2	0D3	1A
ROOTF1	1	1	1	1	1	1	1
ROOTF2	0.5	0.5	1	1	1	1	0.5
ROOTF3	0.2	0.2	0.8	0.8	0.8	0.8	0.2
ROOTF4	0.01	0.01	0.5	0.5	0.5	0.5	0.01
MAXWGT1	1	1	1	1	1	1	1
MAXWGT2	0.8	0.8	1	1	1	1	0.8
MAXWGT3	0.2	0.2	0.8	0.8	0.8	0.8	0.2
MAXWGT4	0.05	0.05	0.25	0.25	0.25	0.25	0.05
RDEPTH1	0.3	0.3	0.15	0.15	0.15	0.15	0.3
RDEPTH2	1.5	1.5	2.5	2.5	2.5	2.5	1.5
RDEPTH4	2	2	3	3	3	3	2
RDEPTHF	2	2	2	2	2	2	2
RKPOR	0.02	0.02	0.02	0.02	0.02	0.02	0
RKMMFACT	1	1	1	1	1	1	1
FLAREA	0.5	0.5	0.15	0.15	0.15	0.15	0.5
INFMOD	1	1	1	1	1	1	1
ETMOD	1	1	1	1	1	1	1
RUNFLOW	0	0	0	0	0	0	0
BARSOIL1	-10	-10	-10	-10	-10	-10	-10
BARSOIL2	1.04	1.04	1.04	1.04	1.04	1.04	1.04
IAIRTEMPT	1	1	3	3	3	3	1
ATEMP1	17.3	17.3	17.3	17.3	17.3	17.3	17.3
ATEMP2	11.74	11.74	11.74	11.74	11.74	11.74	11.74
HSTEP	2	2	2	2	2	2	2
PPTYUC	1	3	5	5	5	5	1
AAPREPX	181	181	181	181	181	181	181
IPPTDAT	0	1	3	3	3	3	0
PPTFILE	mod3-ppt.dat	4ja.s01	Rosalia.inp	Rosalia.inp	Rosalia.inp	Rosalia.inp	mod3-ppt.dat
DEPTHFLG	0	0	0	0	0	0	0
IRTZ	1	1	1	1	1	1	1
DELVWCF	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MOISTCR	1	1	1	1	1	1	1
FRACMOD	1	1	1	1	1	1	1
IVWCFLG	0	0	0	0	0	0	0
VWCFACT	1.2	1.2	2	2	2	2	0
INFILE	t1.w20	t1.w20	t1.w20	Jr2.W20	Jr3.W20	Sc2.W20	t1.w20
LOCSTART	-1	-1	-1	-1	-1	-1	-1
DAYALL	test0a.v21	test0b.v21	test0c.v21	Test0d1.v21	Test0d2.v21	Test0d3.v21	test1a.v21
NDAYMAP	1	1	4	1	1	1	1
IMAP	1	1	1	1	1	1	1
IRDAY	70	70	41	45	45	45	70
NYROUT	1995	1995	1952	1981	1981	1981	1995
DAYMAP	test0a.v22	test0b.v22	test0c1.v22	Test0d1.v22	Test0d2.v22	Test0d3.v22	test1a.v22
OUTFILE	test0a.v23	test0b.v23	test0c.v23	Test0d1.v23	Test0d2.v23	Test0d3.v23	test1a.v23
FLXFILE	test0a.v24	test0b.v24	test0c.v24	Test0d1.v24	Test0d2.v24	Test0d3.v24	test1a.v24
DBGFLAG	1	1	1	1	1	1	1
DBGFLAG2	1	1	1	1	1	1	1
DBGFILE	test0a.v25	test0b.v25	test0c.v25	Test0d1.v25	Test0d2.v25	Test0d3.v25	test1a.v25
IDEBUG	0	0	0	0	0	0	0
DBUGOUT	test0a.v26	test0b.v26	test0c.v26	test0d1.v26	test0d2.v26	test0d3.v26	test1a.v26
OUTYEAR1	test0a	test0b	test0c	test0d1	Test0d2	test0d3	test1a

Control File Input Parameter	Test Case						
	0A	0B	0C	0D1	0D2	0D3	1A
SOILID(10)	10	10	10	10	10	10	10
FIELDCAP(10)	0.189	0.189	0.189	0.189	0.189	0.189	0.189
SOILRESID(10)	0.028	0.028	0.028	0.028	0.028	0.028	0.028
SOILPORO(10)	0.322	0.322	0.322	0.322	0.322	0.322	0.322
SOILALBETA(10)	-2.5	-2.5	-4.5	-4.5	-4.5	-4.5	-2.5
SOILTALPHA(10)	1.26	1.26	1.26	1.26	1.26	1.26	1.26
SOILKS(10)	5.70E-05	5.70E-05	5.70E-05	5.70E-05	5.70E-05	5.70E-05	5.70E-05
SOILPE(10)	- 1.08E+0 0	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00
SOILBVAL(10)	3.88	3.88	3.88	3.88	3.88	3.88	3.88
SALPHA(10)	1	1	1	1	1	1	1
SOILVGN(10)	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
SORP(10)	0.037	0.037	0.037	0.037	0.037	0.037	0.037
SOILPOND(10)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
POTIS(10)	- 1.00E+0 2	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02
SOILID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILBVAL(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILBVAL(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NROCKID	129	129	129	129	129	129	129
ROCKALBETA	-1.5	-1.5	-2.5	-2.5	-2.5	-2.5	-1.5
ROCKTALPHA	1.26	1.26	1.26	1.26	1.26	1.26	1.26
IMBIBE(400)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(450)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(500)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Control File Input Parameter	Test Case						
	1B	1C	1D	1E	1F	2A	2B
OPTMASSB	1	1	1	1	1	1	1
IROUT	0	1	1	1	1	1	1
IFRTOL	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08
ISNOW	2	2	2	2	2	2	2
ISNWDOW	2	2	2	2	2	2	2
SNOWPAR1	1.78	1.78	1.78	1.78	1.78	1.78	1.78
ISUBLIM	3	3	3	3	3	3	3
SUBPAR1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SUBPAR2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
IPPTTEST	0	0	0	0	0	0	0
PPTTEST	1	1	1	1	1	1	1
IETTEST	0	0	0	0	0	0	0
ETTEST	0	0	0	0	0	0	0
CELSIZE	30	30	30	30	30	30	30
XCFS	544691	544691	544691	544691	544691	547931	547931
YCFS	4074153	4074153	4074153	4074153	4074153	4077483	4077483
YRBEG	1980	1980	1980	1980	1980	1980	1980
DNBEG	1	1	1	1	1	1	1
YREND	1985	1985	1985	1985	1985	1985	1985
DNEND	365	365	365	365	365	365	365
TYEAR1	0	0	0	0	0	0	0
TYEAR2	1	1	1	1	1	1	1
PPTFACT	0	0	0	0	0	0	0
ETFACT	0	0	0	0	0	1	1
IMBFACT	0	1	1	1	1	1	1
SKSFACT	0	1	1	1	0.0001	1	1
SDFACT	1	1	1	1	1	1	1
IVEGC	0	0	0	0	0	0	0
FVEGC	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ROOTF1	1	1	1	1	1	1	1
ROOTF2	0.5	0.5	0.5	0.5	0.5	0.5	0.5
ROOTF3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ROOTF4	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MAXWGT1	1	1	1	1	1	1	1
MAXWGT2	0.8	0.8	0.8	0.8	0.8	0.8	0.8
MAXWGT3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
MAXWGT4	0.05	0.05	0.05	0.05	0.05	0.05	0.05
RDEPTH1	0	3	0.1	0.1	0.1	0.3	0.3
RDEPTH2	0	0	0.2	0.2	0.2	1.5	1.5
RDEPTH4	0	0	0.5	0.5	0.5	2	2
RDEPTHF	2	0	1	1	1	2	2
RKPOR	0	0	0	0.1	0.1	0.02	0.02
RKMMFACT	1	1	1	1	1	1	1
FLAREA	0.5	0.5	0.5	0.5	0.5	0.5	0.5
INFMOD	1	1	1	1	1	1	1
ETMOD	1	1	1	1	1	1	1
RUNFLOW	0	0	0	0	0	0	0
BARSOIL1	-10	-10	-10	-10	-10	-10	-10
BARSOIL2	1.04	1.04	1.04	1.04	1.04	1.04	1.04
IAIRTEMPT	1	1	1	1	1	1	1
ATEMP1	17.3	17.3	17.3	17.3	17.3	17.3	17.3
ATEMP2	11.74	11.74	11.74	11.74	11.74	11.74	0
HSTEP	2	2	2	2	2	2	2
PPTYUC	1	1	1	1	1	1	1
AAPREPX	181	181	181	181	181	181	181
IPPTDAT	0	0	0	0	0	0	0

Control File Input Parameter	Test Case						
	1B	1C	1D	1E	1F	2A	2B
PPTFILE	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat
DEPTHFLG	0	0	0	0	0	0	0
IRTZ	1	1	1	1	1	1	1
DELVWCF	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MOISTCR	1	1	1	1	1	1	1
FRACMOD	1	1	1	1	1	1	1
IVWCFLG	0	0	0	0	0	0	0
VWCFACT	10	20	20	20	20	1	20
INFILE	t1.w20	t1.w20	t1.w20	t1.w20	t1.w20	t1.w20	t1.w20
LOCSTART	-1	-1	-1	-1	-1	-1	-1
DAYALL	test1b.v2 1	test1c.v21	test1d.v21	test1e.v21	test1f.v21	test2a.v21	test2b.v21
NDAYMAP	1	4	4	4	4	1	1
IMAP	1	1	1	1	1	1	1
IRDAY	1	1	1	1	1	70	70
NYROUT	1980	1980	1980	1980	1980	1995	1995
DAYMAP	test1b.v2 2	test1c.v22	test1d.v22	test1e.v22	test1f.v22	test2a.v22	test2b.v22
OUTFILE	test1b.v2 3	test1c.v23	test1d.v23	test1e.v23	test1f.v23	test2a.v23	test2b.v23
FLXFILE	test1b.v2 4	test1c.v24	test1d.v24	test1e.v24	test1f.v24	test2a.v24	test2b.v24
DBGFLAG	1	1	1	1	1	1	1
DBGFLAG2	1	1	1	1	1	1	1
DBGFILE	test1b.v2 5	test1c.v25	test1d.v25	test1e.v25	test1f.v25	test2a.v25	test2b.v25
IDEBUG	0	0	0	0	0	0	0
DBUGOUT	test1b.v2 6	test1c.v26	test1d.v26	test1e.v26	test1f.v26	test2a.v26	test2b.v26
OUTYEAR1	test1b	test1c	Test1d	Test1e	Test1f	test2a	test2b
SOILID(10)	10	10	10	10	10	10	10
FIELDCAP(10)	0.189	0.189	0.189	0.189	0.189	0.189	0.189
SOILRESID(10)	0.028	0.028	0.028	0.028	0.028	0.028	0.028
SOILPORO(10)	0.322	0.322	0.322	0.322	0.322	0.322	0.322
SOILALBETA(10)	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
SOILTALPHA(10)	1.26	1.26	1.26	1.26	1.26	1.26	1.26
SOILKS(10)	5.70E-05	5.70E-05	5.70E-05	5.70E-05	5.70E-05	5.70E-05	5.70E-05
SOILPE(10)	- 1.08E+0 0	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00
SOILBVAL(10)	3.88	3.88	3.88	3.88	3.88	3.88	3.88
SALPHA(10)	1	1	1	1	1	1	1
SOILVGN(10)	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
SORP(10)	0.037	0.037	0.037	0.037	0.037	0.037	0.037
	1B	1C	1D	1E	1F	2A	2B
SOILPOND(10)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
POTIS(10)	- 1.00E+0 2	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02
SOILID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Control File Input Parameter	Test Case						
	1B	1C	1D	1E	1F	2A	2B
SOILBVAL(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILBVAL(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NROCKID	129	129	129	129	129	129	129
ROCKALBETA	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5
ROCKTALPHA	1.26	1.26	1.26	1.26	1.26	1.26	1.26
IMBIBE(400)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(450)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(500)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Control File Input Parameter	Test Case						
	2C	2D	2E	2F	2G	2H	2I
OPTMASSB	1	1	1	1	1	1	1
IROUT	1	1	1	1	1	1	1
IFRTOL	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08
ISNOW	2	2	2	2	2	2	2
ISNWDOW	2	2	2	2	2	2	2
SNOWPAR1	1.78	1.78	1.78	1.78	1.78	1.78	1.78
ISUBLIM	3	3	3	3	3	3	3
SUBPAR1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SUBPAR2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
IPPTTEST	0	0	0	0	0	0	0
PPTTEST	1	1	1	1	1	1	1
IETTEST	0	0	0	1	1	1	1
ETTEST	0	0	0	5	5	5	2
CELSIZE	30	30	30	30	30	30	30
XCFS	547931	547931	547931	547931	547931	547931	547931
YCFS	4077483	4077483	4077483	4077483	4077483	4077483	4077483
YRBEG	1980	1980	1980	1980	1980	1980	1980
DNBEG	1	1	1	1	1	1	1
YREND	1985	1985	1985	1985	1985	1985	1985
DNEND	365	365	365	365	365	365	365
TYEAR1	0	0	0	0	0	0	0
TYEAR2	1	1	1	1	1	1	1
PPTFACT	0	0	0	0	0	0	0
ETFACT	1	1	1	1	1	1	1
IMBFACT	1	1	1	1	1	1	1
SKSFACT	1	1	1	1	0.000001	0.00001	0.00001
SDFACT	1	1	1	1	1	1	1
IVEGC	0	0	0	0	0	0	0
FVEGC	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ROOTF1	1	1	1	1	1	1	1
ROOTF2	0.5	0.5	0.5	0.5	0.5	0.5	0.5
ROOTF3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ROOTF4	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MAXWGT1	1	1	1	1	1	1	1
MAXWGT2	0.8	0.8	0.8	0.8	0.8	0.8	0.8
MAXWGT3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
MAXWGT4	0.05	0.05	0.05	0.05	0.05	0.05	0.05
RDEPTH1	0.3	0.3	0.3	0.3	0.3	0.3	0.3
RDEPTH2	1.5	1.5	1.5	1.5	1.5	1.5	1.5
RDEPTH4	2	2	2	2	2	2	2
RDEPTHF	2	2	2	2	2	2	2
RKPOR	0.02	0.02	0.02	0.02	0.02	0.02	0.02
RKMMFACT	1	1	1	1	1	1	1
FLAREA	0.5	0.5	0.5	0.5	0.5	0.5	0.5
INFMOD	1	1	1	1	1	1	1
ETMOD	1	1	1	1	1	1	1
RUNFLOW	0	0	0	0	0	0	0
BARSOIL1	-10	-10	-10	-10	-10	-10	-10
BARSOIL2	1.04	1.04	1.04	1	1	1	1
IAIRTEMPT	1	1	1	1	1	1	1
ATEMP1	0	0	0	17.3	17.3	17.3	17.3
ATEMP2	0	0	0	11.74	11.74	11.74	11.74
HSTEP	2	2	2	2	2	2	2
PPTYUC	1	1	1	1	1	1	1
AAPREPX	181	181	181	181	181	181	181

Control File Input Parameter	Test Case						
	2C	2D	2E	2F	2G	2H	2I
IPPTDAT	0	0	0	0	0	0	0
PPTFILE	mod3-ppt.dat	test2d.dat	test2e.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat
DEPTHFLG	0	0	0	0	0	0	0
IRTZ	1	1	1	1	1	1	1
DELVWCF	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MOISTCR	1	1	1	1	1	1	1
FRACMOD	1	1	1	1	1	1	1
IVWCFLG	0	0	0	0	0	0	0
VWCFACT	20	20	20	4	4	4	4
INFILE	t1.w20	t1.w20	t1.w20	t1a.w20	t1a.w20	t1a.w20	t1a.w20
LOCSTART	-1	-1	-1	-1	-1	-1	-1
DAYALL	test2c.v21	test2d.v21	test2e.v21	test2f.v21	test2g.v21	test2h.v21	test2i.v21
NDAYMAP	1	1	1	7	7	7	7
IMAP	1	1	1	1	1	1	1
IRDAY	70	70	70	1	1	1	1
NYROUT	1995	1995	1995	1980	1980	1980	1980
DAYMAP	test2c.v22	test2d.v22	test2e.v22	test2f1.v22	test2g1.v22	test2h1.v22	test2i1.v22
OUTFILE	test2c.v23	test2d.v23	test2e.v23	test2f.v23	test2g.v23	test2h.v23	test2i.v23
FLXFILE	test2c.v24	test2d.v24	test2e.v24	test2f.v24	test2g.v24	test2h.v24	test2i.v24
DBGFLAG	1	1	1	1	1	1	1
DBGFLAG2	1	1	1	1	1	1	1
DBGFILE	test2c.v25	test2d.v25	test2e.v25	test2f.v25	test2g.v25	test2h.v25	test2i.v25
IDEBUG	0	0	0	0	0	0	0
DBUGOUT	test2c.v26	test2d.v26	test2e.v26	test2f.v26	test2g.v26	test2h.v26	test2i.v26
OUTYEAR1	test2c	test2d	test2e	test2f	test2g	test2h	test2i
SOILID(10)	10	10	10	10	10	10	10
FIELDCAP(10)	0.189	0.189	0.189	0.1	0.1	0.1	0.1
SOILRESID(10)	0.028	0.028	0.028	0.1	0.1	0.1	0.1
SOILPORO(10)	0.322	0.322	0.322	0.3	0.3	0.3	0.3
SOILALBETA(10)	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
SOILTALPHA(10)	1.26	1.26	1.26	1	1	1	1
SOILKS(10)	5.70E-05	5.70E-05	5.70E-05	1.00E-01	1.00E-01	1.00E-01	1.00E-01
SOILPE(10)	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00
SOILBVAL(10)	3.88	3.88	3.88	3.88	3.88	3.88	3.88
SALPHA(10)	1	1	1	1	1	1	1
SOILVGN(10)	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
SORP(10)	0.037	0.037	0.037	0.037	0.037	0.037	0.037
SOILPOND(10)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
POTIS(10)	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02
SOILID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Control File Input Parameter	Test Case						
	2C	2D	2E	2F	2G	2H	2I
SOILBVAL(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILBVAL(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NROCKID	129	129	129	130	130	130	130
ROCKALBETA	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5
ROCKTALPHA	1.26	1.26	1.26	1	1	1	1
IMBIBE(400)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(450)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(500)	N/A	N/A	N/A	1.00	1.00	1.00	1.00

Control File Input Parameter	Test Case						
	2J	2K	3A	3B	3C	3D	3E
OPTMASSB	1	1	0	1	1	1	1
IROUT	1	1	1	1	1	1	1
IFRTOL	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08
ISNOW	2	2	2	2	2	2	2
ISNWDOW	2	2	2	2	2	2	2
SNOWPAR1	1.78	1.78	1.78	1.78	1.78	1.78	1.78
ISUBLIM	3	3	3	3	3	3	3
SUBPAR1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SUBPAR2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
IPPTTEST	0	0	1	1	1	1	1
PPTTEST	1	1	10	10	10	10	10
IETTEST	1	1	0	0	0	1	1
ETTEST	2	2	2	2	2	2	5
CELSIZE	30	30	30	30	30	30	30
XCFS	547931	547931	547931	547931	547931	547931	547931
YCFS	4077483	4077483	4077483	4077483	4077483	4077483	4077483
YRBEG	1980	1980	1980	1980	1980	1980	1980
DNBEG	1	1	1	1	1	1	1
YREND	1985	1985	1985	1985	1985	1985	1985
DNEND	365	365	365	365	365	365	365
TYEAR1	0	0	0	0	0	0	0
TYEAR2	1	1	1	1	1	1	1
PPTFACT	0	0	1	1	1	1	1
ETFACT	1	1	0	0	0	0	0
IMBFACT	1	1	1	1	1	1	5
SKSFACT	1	1	1	0.0001	0.0001	0.0001	1
SDFACT	2	2	2	2	0.1	0.1	1
IVEGC	0	0	0	0	0	0	0
FVEGC	0.2	0.2	0.2	0.2	0.2	0	0
ROOTF1	1	0	1	1	1	0	0
ROOTF2	0	1	1	1	1	1	0
ROOTF3	0	0	1	1	1	1	1
ROOTF4	0	1	1	1	1	1	1
MAXWGT1	1	0	1	1	1	0	0
MAXWGT2	0	1	1	1	1	1	0
MAXWGT3	0	0	1	1	1	1	1
MAXWGT4	0	1	1	1	1	1	1
RDEPTH1	0.3	0.3	0.3	0.3	0.3	0.3	0.3
RDEPTH2	1	1	1	1	1	1	1
RDEPTH4	3	3	3	3	3	3	3
RDEPTHF	2	2	2	2	2	2	2
RKPOR	0.02	0.02	0.02	0.02	0.001	0.001	0.01
RKMMFACT	1	1	1	1	1	1	1
FLAREA	0.5	0.5	0.5	0.5	0.5	0.5	0.5
INFMOD	1	1	1	1	1	1	1
ETMOD	1	1	1	1	1	1	1
RUNFLOW	0	0	0	0	0	0	0
BARSOIL1	-10	-10	-10	-10	-10	-10	-10
BARSOIL2	1	1	1	1	1	1	1
IAIRTEMPT	1	1	1	1	1	1	1
ATEMP1	17.3	17.3	17.3	17.3	17.3	17.3	17.3
ATEMP2	11.74	11.74	11.74	11.74	11.74	11.74	11.74
HSTEP	2	2	2	2	2	2	2
PPTYUC	1	1	1	1	1	1	1
AAPREPX	181	181	181	181	181	181	181

Control File Input Parameter	Test Case						
	2J	2K	3A	3B	3C	3D	3E
IPPTDAT	0	0	0	0	0	0	0
PPTFILE	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat
DEPTHFLG	0	0	0	0	0	0	0
IRTZ	1	1	1	1	1	1	1
DELVWCF	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MOISTCR	1	1	1	1	1	1	1
FRACMOD	1	1	1	1	1	1	1
IVWCFLG	0	0	0	0	0	0	0
VWCFACT	4	4	1	1	1	1	1
INFILE	t1a.w20	t1a.w20	t1a.w20	t1a.w20	t1a.w20	t1a.w20	t1a.w20
LOCSTART	-1	-1	-1	-1	-1	-1	-1
DAYALL	test2j.v21	test2k.v21	test3a.v21	test3b.v21	test3c.v21	test3d.v21	test3e.v21
NDAYMAP	7	7	7	7	7	7	7
IMAP	1	1	1	1	1	1	1
IRDAY	1	1	1	1	1	1	1
NYROUT	1980	1980	1980	1980	1980	1980	1980
DAYMAP	test2j1.v2 2	test2k1.v2 2	test3a1.v2 2	test3b1.v22	test3c1.v2 2	test3d1.v22	test3e1.v22
OUTFILE	test2j.v23	test2k.v23	test3a.v23	test3b.v23	test3c.v23	test3d.v23	test3e.v23
FLXFILE	test2j.v24	test2k.v24	test3a.v24	test3b.v24	test3c.v24	test3d.v24	test3e.v24
DBGFLAG	1	1	1	1	1	1	1
DBGFLAG2	1	1	1	1	1	1	1
DBGFILE	test2j.v25	test2k.v25	test3a.v25	test3b.v25	test3c.v25	test3d.v25	test3e.v25
IDEBUG	0	0	0	0	0	0	0
DBUGOUT	test2j.v26	test2k.v26	test3a.v26	test3b.v26	test3c.v26	test3d.v26	test3e.v26
OUTYEAR1	test2j	test2k	test3a	test3b	test3c	test3d	test3e
SOILID(10)	10	10	10	10	10	10	10
FIELDCAP(10)	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SOILRESID(10)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SOILPORO(10)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
SOILALBETA(10)	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
SOILTALPHA(10)	1	1	1	1	1	1	1
SOILKS(10)	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
SOILPE(10)	- 1.08E+0 0	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00
SOILBVAL(10)	3.88	3.88	3.88	3.88	3.88	3.88	3.88
SALPHA(10)	1	1	1	1	1	1	1
SOILVGN(10)	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
SORP(10)	0.037	0.037	0.037	0.037	0.037	0.037	0.037
SOILPOND(10)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
POTIS(10)	- 1.00E+0 2	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02
SOILID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILBVAL(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Control File Input Parameter	Test Case						
	2J	2K	3A	3B	3C	3D	3E
SOILPOND(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(12)	N/A	N/A,	N/A	N/A	N/A	N/A	N/A
SOILPORO(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILBVAL(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NROCKID	130	130	130	130	130	130	130
ROCKALBETA	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5
ROCKTALPHA	1	1	1	1	1	1	1
IMBIBE(400)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(450)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(500)	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Control File Input Parameter	Test Case						
	3F	3G	4A	4B	4C	4D	4E
OPTMASSB	1	1	1	1	1	1	1
IROUT	1	1	1	1	1	1	1
IFRTOL	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08
ISNOW	2	2	2	2	2	2	2
ISNWDOW	2	2	2	2	2	2	2
SNOWPAR1	1.78	1.78	1.78	1.78	1.78	1.78	1.78
ISUBLIM	3	3	3	3	3	3	3
SUBPAR1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SUBPAR2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
IPPTTEST	1	1	1	1	1	0	0
PPTTEST	10	10	10	10	10	10	10
IETTEST	1	1	0	0	0	0	1
ETTEST	5	5	5	5	5	5	5
CELSIZE	30	30	30	30	30	30	30
XCFS	547931	547931	547931	547931	547931	547931	547931
YCFS	4077483	4077483	4077483	4077483	4077483	4077483	4077483
YRBEG	1980	1980	1980	1980	1980	1980	1980
DNBEG	1	1	1	1	1	1	1
YREND	1985	1985	1985	1985	1985	1985	1985
DNEND	365	365	365	365	365	365	365
TYEAR1	0	0	0	0	0	0	0
TYEAR2	1	1	1	1	1	1	1
PPTFACT	1	1	1	1	1	1	1
ETFACT	0	0	0	0	0	0	0
IMBFACT	5	5	0	1	1	1	1
SKSFACT	1	1	1	1000	1000	1	1
SDFACT	1	2	2	1	1	1	1
IVEGC	0	0	0	0	0	0	0
FVEGC	0	0	0	0	0	0	0
ROOTF1	1	1	1	1	1	1	1
ROOTF2	1	0.5	1	1	1	1	0.5
ROOTF3	1	0.1	1	1	1	1	0.1
ROOTF4	0.1	0.01	0.1	0.1	0.1	0.1	0
MAXWGT1	1	1	1	1	1	1	1
MAXWGT2	1	0.5	1	1	1	1	0.5
MAXWGT3	1	0.1	1	1	1	1	0.1
MAXWGT4	0.1	0.01	0.1	0.1	0.1	0.1	0
RDEPTH1	0.3	0.3	0.3	0.3	0.3	0.1	0.1
RDEPTH2	1	1	1	1	1	1	1
RDEPTH4	3	3	3	3	3	3	3
RDEPTHF	2	2	2	2	2	2	2
RKPOR	0.01	0.02	0.1	0.1	0.1	0.1	0.01
RKMMFACT	1	1	1	1	1	1	1
FLAREA	0.5	0.5	0.5	1	0.00001	1	1
INFMOD	1	1	1	1	1	1	1
ETMOD	1	1	1	1	1	1	1
RUNFLOW	0	0	0	0	0	0	0
BARSOIL1	-10	-10	-10	-10	-10	-10	-10
BARSOIL2	1	1	1	1	1	1	1
IAIRTEMPT	1	1	1	1	1	1	1
ATEMP1	17.3	17.3	17.3	17.3	17.3	17.3	17.3
ATEMP2	11.74	11.74	11.74	11.74	11.74	11.74	11.74
HSTEP	2	2	2	2	2	2	2
PPTYUC	1	1	1	1	1	1	1
AAPREPX	181	181	181	181	181	181	181

Control File Input Parameter	Test Case						
	3F	3G	4A	4B	4C	4D	4E
IPPTDAT	0	0	0	0	0	0	0
PPTFILE	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	Test4d.dat	Test4d.dat
DEPTHFLG	0	0	0	0	0	0	0
IRTZ	1	1	1	1	1	1	1
DELVWCF	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MOISTCR	1	1	1	1	1	1	1
FRACMOD	1	1	1	1	1	1	1
IVWCFLG	0	0	0	0	0	0	0
VWCFACT	1	1	1	1	1	1	1
INFILE	t1a.w20	t1a.w20	t1b.w20	t1b.w20	t1b.w20	t1b.w20	t1c.w20
LOCSTART	-1	-1	-1	-1	-1	-1	-1
DAYALL	test3f.v21	test3g.v21	test4a.v21	test4b.v21	test4c.v21	test4d.v21	test4e.v21
NDAYMAP	7	7	7	7	10	10	10
IMAP	1	1	1	1	1	1	1
IRDAY	1	1	1	1	1	1	1
NYROUT	1980	1980	1980	1980	1980	1980	1980
DAYMAP	test3f1.v22	test3g1.v22	test4a1.v22	test4b1.v22	test4c1.v22	test4d1.v22	test4e1.v22
OUTFILE	test3f.v23	test3g.v23	test4a.v23	test4b.v23	test4c.v23	test4d.v23	test4e.v23
FLXFILE	test3f.v24	test3g.v24	test4a.v24	test4b.v24	test4c.v24	test4d.v24	test4e.v24
DBGFLAG	1	1	1	1	1	1	1
DBGFLAG2	1	1	1	1	1	1	1
DBGFILE	test3f.v25	test3g.v25	test4a.v25	test4b.v25	test4c.v25	test4d.v25	test4e.v25
IDEBUG	0	0	0	0	0	0	0
DBUGOUT	test3f.v26	test3g.v26	test4a.v26	test4b.v26	test4c.v26	test4d.v26	test4e.v26
OUTYEAR1	test3f	test3g	test4a	test4b	test4c	test4d	test4e
SOILID(10)	10	10	10	10	10	10	10
FIELDCAP(10)	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SOILRESID(10)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SOILPORO(10)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
SOILALBETA(10)	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
SOILTALPHA(10)	1	1	1	1	1	1	1
SOILKS(10)	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
SOILPE(10)	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00
SOILBVAL(10)	3.88	3.88	3.88	3.88	3.88	3.88	3.88
SALPHA(10)	1	1	1	1	1	1	1
SOILVGN(10)	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
SORP(10)	0.037	0.037	0.037	0.037	0.037	0.037	0.037
SOILPOND(10)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
POTIS(10)	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02
SOILID(11)	N/A	N/A	11	11	11	11	11
FIELDCAP(11)	N/A	N/A	0.2	0.2	0.2	0.2	0.2
SOILRESID(11)	N/A	N/A	0.1	0.1	0.1	0.1	0.1
SOILPORO(11)	N/A	N/A	0.3	0.3	0.3	0.3	0.3
SOILALBETA(11)	N/A	N/A	-2.5	-2.5	-2.5	-2.5	-2.5
SOILTALPHA(11)	N/A	N/A	1	1	1	1	1
SOILKS(11)	N/A	N/A	1.00E-04	1.00E-04	1.00E-04	1.00E-02	1.00E-03
SOILPE(11)	N/A	N/A	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00

Control File Input Parameter	Test Case						
	3F	3G	4A	4B	4C	4D	4E
SOILBVAL(11)	N/A	N/A	3.88	3.88	3.88	3.88	3.88
SALPHA(11)	N/A	N/A	1	1	1	1	1
SOILVGN(11)	N/A	N/A	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
SORP(11)	N/A	N/A	0.037	0.037	0.037	0.037	0.037
SOILPOND(11)	N/A	N/A	0.05	0.05	0.05	0.05	0.05
POTIS(11)	N/A	N/A	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02
SOILID(12)	N/A	N/A	N/A	N/A	N/A	N/A	12
FIELDCAP(12)	N/A	N/A	N/A	N/A	N/A	N/A	0.2
SOILRESID(12)	N/A	N/A	N/A	N/A	N/A	N/A	0.1
SOILPORO(12)	N/A	N/A	N/A	N/A	N/A	N/A	0.3
SOILALBETA(12)	N/A	N/A	N/A	N/A	N/A	N/A	-2.5
SOILTALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	1
SOILKS(12)	N/A	N/A	N/A	N/A	N/A	N/A	1.00E-02
SOILPE(12)	N/A	N/A	N/A	N/A	N/A	N/A	-1.08E+00
SOILBVAL(12)	N/A	N/A	N/A	N/A	N/A	N/A	3.88
SALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	1
SOILVGN(12)	N/A	N/A	N/A	N/A	N/A	N/A	5.50E-01
SORP(12)	N/A	N/A	N/A	N/A	N/A	N/A	0.037
SOILPOND(12)	N/A	N/A	N/A	N/A	N/A	N/A	0.05
POTIS(12)	N/A	N/A	N/A	N/A	N/A	N/A	-1.00E+02
NROCKID	130	130	131	131	131	131	132
ROCKALBETA	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5
ROCKTALPHA	1	1	1	1	1	1	1
IMBIBE(400)	N/A	N/A	1.00	5.00	5.00	1.00	100.00
IMBIBE(450)	N/A	N/A	N/A	N/A	N/A	N/A	10.00
IMBIBE(500)	1.00	1.00	1.00	0.00	0.00	1.00	1.00

Control File Input Parameter	Test Case						
	4F	5A	5B	5C	5D		
OPTMASSB	1	0	0	1	1		
IROUT	1	0	0	1	1		
IFRTOL	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08		
ISNOW	2	2	2	2	2		
ISNWDOW	2	2	2	2	2		
SNOWPAR1	1.78	1.78	1.78	1.78	1.78		
ISUBLIM	3	3	3	3	3		
SUBPAR1	0.1	0.1	0.1	0.1	0.1		
SUBPAR2	0.3	0.3	0.3	0.3	0.3		
IPPTTEST	0	1	1	1	1		
PPTTEST	10	1	1	2	2		
IETTEST	1	0	0	0	0		
ETTEST	5	1	1	1	1		
CELSIZE	30	30	30	30	30		
XCFS	547931	547931	547931	547931	547931		
YCFS	4077483	4077483	4077483	4077483	4077483		
YRBEG	1980	1980	1980	1980	1980		
DNBEG	1	1	1	1	1		
YREND	1985	1985	1985	1985	1985		
DNEND	365	365	365	365	365		
TYEAR1	0	0	0	0	0		
TYEAR2	1	1	1	1	1		
PPTFACT	1	1	1	1	1		
ETFACT	0	1	1	1	1		
IMBFACT	1	1	1	1	1		
SKSFACT	1	1	1	1	1		
SDFACT	1	1	1	1	1		
IVEGC	0	0	0	0	0		
FVEGC	0	0	0	0	0		
ROOTF1	0	1	1	1	1		
ROOTF2	0.1	1	1	1	1		
ROOTF3	0.5	1	1	1	1		
ROOTF4	1	1	1	1	1		
MAXWGT1	0	1	1	1	1		
MAXWGT2	0.1	1	1	1	1		
MAXWGT3	0.5	1	1	1	1		
MAXWGT4	1	1	1	1	1		
RDEPTH1	0.1	0.1	0.1	0.1	0.1		
RDEPTH2	1	1	1	1	1		
RDEPTH4	3	2	2	2	2		
RDEPTHF	2	2	2	2	2		
RKPOR	0.01	0.1	0.1	0.1	0.1		
RKMMFACT	1	1	1	1	1		
FLAREA	1	0.5	0.5	0.5	0.5		
INFMOD	1	1	1	1	1		
ETMOD	1	1	1	1	1		
RUNFLOW	0	0	0	0	0		
BARSOIL1	-10	-10	-10	-10	-10		
BARSOIL2	1	1	1	1	1		
IAIRTEMPT	1	1	1	1	1		
ATEMP1	17.3	-50	-10	-0.6	-0.6		
ATEMP2	11.74	0	0	0	20		
HSTEP	2	2	2	2	2		
PPTYUC	1	1	1	1	1		
AAPREPX	181	181	181	181	181		

Control File Input Parameter	Test Case						
	4F	5A	5B	5C	5D		
IPPTDAT	0	0	0	0	0		
PPTFILE	Test4d.dat	mod3- ppt.dat	mod3- ppt.dat	mod3- ppt.dat	mod3- ppt.dat		
DEPTHFLG	0	0	0	0	0		
IRTZ	1	1	1	1	1		
DELVWCF	0.5	0.5	0.5	0.5	0.5		
MOISTCR	1	1	1	1	1		
FRACMOD	1	1	1	1	1		
IVWCFLG	0	0	0	0	0		
VWCFACT	1	1	1	1	1		
INFILE	t1c.w20	t1a.w20	t1a.w20	t1a.w20	t1a.w20		
LOCSTART	-1	-1	-1	-1	-1		
DAYALL	test4f.v21	test5a.v21	test5b.v2 1	test5c.v21	test5d.v21		
NDAYMAP	10	1	1	1	1		
IMAP	1	1	1	1	1		
IRDAY	1	70	70	70	70		
NYROUT	1980	1995	1995	1995	1995		
DAYMAP	test4f1.v2 2	test5a.v22	test5b.v2 2	test5c.v22	test5d.v22		
OUTFILE	test4f.v23	test5a.v23	test5b.v2 3	test5c.v23	test5d.v23		
FLXFILE	test4f.v24	test5a.v24	test5b.v2 4	test5c.v24	test5d.v24		
DBGFLAG	1	1	1	1	1		
DBGFLAG2	1	1	1	1	1		
DBGFILE	test4f.v25	test5a.v25	test5b.v2 5	test5c.v25	test5d.v25		
IDEBUG	0	0	0	0	0		
DBUGOUT	test4f.v26	test5a.v26	test5b.v2 6	test5c.v26	test5d.v26		
OUTYEAR1	test4f	test5a	test5b	test5c	test5d		
SOILID(10)	10	10	10	10	10		
FIELDCAP(10)	0.2	0.2	0.2	0.2	0.2		
SOILRESID(10)	0.1	0.1	0.1	0.1	0.1		
SOILPORO(10)	0.3	0.3	0.3	0.3	0.3		
SOILALBETA(10)	-2.5	-2.5	-2.5	-2.5	-2.5		
SOILTALPHA(10)	1	1	1	1	1		
SOILKS(10)	1.00E-04	5.70E-05	5.70E-05	5.70E-05	1.00E-03		
SOILPE(10)	-1.08E+00	-1.08E+00	- 1.08E+0 0	-1.08E+00	-1.08E+00		
SOILBVAL(10)	3.88	3.88	3.88	3.88	3.88		
SALPHA(10)	1	1	1	1	1		
SOILVGN(10)	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01		
SORP(10)	0.037	0.037	0.037	0.037	0.037		
SOILPOND(10)	0.05	0.05	0.05	0.05	0.05		
POTIS(10)	-1.00E+02	-1.00E+02	- 1.00E+0 2	-1.00E+02	-1.00E+02		
SOILID(11)	11	N/A	N/A	N/A	N/A		
FIELDCAP(11)	0.2	N/A	N/A	N/A	N/A		
SOILRESID(11)	0.1	N/A	N/A	N/A	N/A		
SOILPORO(11)	0.3	N/A	N/A	N/A	N/A		
SOILALBETA(11)	-2.5	N/A	N/A	N/A	N/A		
SOILTALPHA(11)	1	N/A	N/A	N/A	N/A		
SOILKS(11)	1.00E-03	N/A	N/A	N/A	N/A		
SOILPE(11)	-1.08E+00	N/A	N/A	N/A	N/A		

Control File Input Parameter	Test Case						
	4F	5A	5B	5C	5D		
SOILBVAL(11)	3.88	N/A	N/A	N/A	N/A		
SALPHA(11)	1	N/A	N/A	N/A	N/A		
SOILVGN(11)	5.50E-01	N/A	N/A	N/A	N/A		
SORP(11)	0.037	N/A	N/A	N/A	N/A		
SOILPOND(11)	0.05	N/A	N/A	N/A	N/A		
POTIS(11)	-1.00E+02	N/A	N/A	N/A	N/A		
SOILID(12)	12	N/A	N/A	N/A	N/A		
FIELDCAP(12)	0.2	N/A	N/A	N/A	N/A		
SOILRESID(12)	0.1	N/A	N/A	N/A	N/A		
SOILPORO(12)	0.3	N/A	N/A	N/A	N/A		
SOILALBETA(12)	-2.5	N/A	N/A	N/A	N/A		
SOILTALPHA(12)	1	N/A	N/A	N/A	N/A		
SOILKS(12)	1.00E-02	N/A	N/A	N/A	N/A		
SOILPE(12)	-1.08E+00	N/A	N/A	N/A	N/A		
SOILBVAL(12)	3.88	N/A	N/A	N/A	N/A		
SALPHA(12)	1	N/A	N/A	N/A	N/A		
SOILVGN(12)	5.50E-01	N/A	N/A	N/A	N/A		
SORP(12)	0.037	N/A	N/A	N/A	N/A		
SOILPOND(12)	0.05	N/A	N/A	N/A	N/A		
POTIS(12)	-1.00E+02	N/A	N/A	N/A	N/A		
NROCKID	132	130	130	130	130		
ROCKALBETA	-1.5	-1.5	-1.5	-1.5	-1.5		
ROCKTALPHA	1	1	1	1	1		
IMBIBE(400)	100.00	N/A	N/A	N/A	N/A		
IMBIBE(450)	10.00	N/A	N/A	N/A	N/A		
IMBIBE(500)	1.00	0.24	0.24	1.00	1.00		

(N/A, Not applicable)

APPENDIX 1-B. DAILY CLIMATE INPUT FILE:

The daily climate input file is the primary control for the timing and duration of the simulation. The daily climate input file defines the time domain through which the simulation occurs by providing a real-time sequential input of daily climate parameters. The file at minimum consists of the year number, the day of year number, and the total daily precipitation amount but can also consist of maximum, minimum, and average daily air temperature, along with total daily snowfall accumulation. The three options for daily climate input used for the Yucca Mountain Project are as follows:

1. Development of a daily climate input file (mod3-ppt.dat) for model calibration and modern climate simulations using available precipitation records from monitoring sites within the study area and in the proximity of Yucca Mountain. Development of mod3-ppt.dat is performed within an EXCEL spreadsheet (mod3-ppt.xls) using a linear interpolation method.

2. Development of 100-year daily climate input files for modern climate scenarios using available precipitation records from the Nevada Test Site stations 4JA and Area 12 Mesa and the programs MARKOV V1.0 (STN 10142-1.0-00) and PPTSIM V1.0. (STN 10143-1.0-00).

3. Development of daily climate input for future climate scenarios using the routine DAILY09 V1.0 and seven selected analog records from the EARTHINFO[1] database.

A. Precipitation Input Variable Order

```
      open(unit=11,file=pptfile)
         if(ipptdat.eq.3) then
               do i = 1,33
                     read(11,5) header0
               enddo
         endif
               if(ipptdat.eq.3) then
read(11,8011,end=90) icalday,yr(nd),month(nd),day(nd),
         1                  dn(nd),ppt(nd),dayflg,maxairt(nd),
         2            dayflg,minairt(nd),dayflg,avgairt(nd),
   3                  dayflg,snowdat,dayflg
  c
  8011                format(i8,i5,i3,i3,i5,6(f7.1,a3))
  c
               else if(ipptdat.eq.1) then
         read(11,*,end=90) month(nd),day(nd),yr(nd),dn(nd),ppt(nd)
  c
       else
         read(11,*,end=90) yr(nd),dn(nd),ppt(nd)
                     yr(nd) = 1900 + yr(nd)
                     month(nd) = -9
```

[1] EARTHINFO is a registered trademark of EarthInfo Inc., 5541 Central Avenue, Boulder, CO 80301.

```
        day(nd) = -9
    endif
```

B. Daily climate input file variables.

Precipitation InputParameter	Description	Format
[If IPPTDAT = 0]	Variable determining input source selects daily data from a single site.	N/A
YR	Year of measurement	* (List-directed I/O)
DN	Day of year (Julian day)	*
PPT	Precipitation (mm)	*
[If IPPTDAT = 1]	Variable determining input source selects data produced from PPTSIM module.	N/A
MONTH	Month of year	
DAY	Day of year	*
YR	Year of measurement	*
DN	Day of year (Julian day)	*
PPT	Precipitation (mm)	*
[If IPPTDAT = 3]	Variable determining input source selects data produced from DAILY09 module.	N/A
HEADER0	Descriptions of variables below	A (Character data)
ICALDAY	Record day number	FORMAT statement 8011 (see below)
YR	Year of measurement	8011
MONTH	Month of year	8011
DAY	Day of year	8011
DN	Day of year (Julian day)	8011
PPT	Precipitation (mm)	8011
DAYFLG	Data Flags:-999.9 = missing dataM = missing data flagA = accumulated measurement (multiple days)T = trace amount (less than measurement resolution)C1 = calculated value (type 1 calculation)E1 = estimated value (type 1 estimation)E2 = estimated value (type 2 estimation)E3 = estimated value (type 3 estimation)	8011
MAXAIRT	Maximum air temperature (deg. C) of day	8011
DAYFLG	As above.	8011
MINAIRT	Minimum air temperature (deg. C) of day	8011
DAYFLG	As above.	8011
AVGAIRT	Average air temperature (deg. C) of day	8011
DAYFLG	As above.	8011
SNOWDAT	Snow (mm)	8011
DAYFLG	As above.	8011

Note: 8011, format(i8,i5,i3,i3,i5,6(f7.1,a3))

C. Examples for Precipitation Input Data Files.

There are three types of daily climate input files. These are described below.

1. Yucca Mountain 1980-95 Developed Daily Precipitation Record (mod3-ppt.dat)

a. Statement of Intended Use for the Data

The purpose of these data is to provide a temporal record of precipitation at one point on Yucca Mountain for the time period 1980 through 1995. These data represent a point near the center of Yucca Mountain approximately 1400 m in elevation and will be used to spatially distribute precipitation over the site area using correlations with elevation in order to (1) calibrate the net infiltration model, and (2) develop net infiltration results for the modern climate scenarios, which are used as input for UZ ground-water flow and transport models for TSPA.

b. General Information Pertaining to the Data Set

The climate input file used for model calibration, MOD3-PPT.DAT, is the same developed daily precipitation record that was used for calibration of the original 1996 (INFIL V1.0) net infiltration model for Yucca Mountain (Flint et al., 1996, Figure 19, DTN: GS960908312211.003). The file MOD3-PPT.DAT consists of daily precipitation estimates only and was developed using source data of daily precipitation records from 1980 through 1995.

<u>i. Source data (all data used is shown in Excel file MOD3-PPT.xls)</u>

USGS Yucca Mountain precipitation data from weatherstations WX1 and WX3.
GS960908312111.004 (1995 water year)
GS970108312111.001 (Oct. 1- Dec. 3, 1995)
GS000208312111.003 (1987-1989, non-Q)
GS000208312111.001 (1989-1994)

Nevada Test Site (NTS) precipitation data for stations 4JA, 40MN, Rock Valley, Cane Spring, Mid Valley and Tippipah Spring #2. These data are available in DTN: GS000200001221.002.

National Weather Service (NWS) stations at Beatty 8N and Amargosa Farms, from the National Climate Data Center and available through EarthInfo (see information provided in DTN: GS000100001221.001).

<u>ii. Development of daily precipitation record</u>

The developed record of daily precipitation is only an approximate representation of actual conditions over the general location and ground surface elevation of the potential repository area. Daily precipitation estimates for 1988 through 1995 were developed using the mean of the data from the Yucca Mountain weatherstations. For 1980 through 1987, daily precipitation was estimated using a linear interpolation model and available precipitation records from the six Nevada Test Site (NTS) monitoring sites and the two National Weather Service (NWS) monitoring sites located near Yucca Mountain. The model was developed using linear regression of a weighted mean daily precipitation calculated from the eight stations against the mean calculated from the two USGS weather stations for the period July 17, 1987 through September 30, 1994 (this is the period for which the two sets of records overlapped).

Table III-1 in USGS (2001) is the developed data precipitation record for Yucca Mountain that was used directly as input for INFIL V2.0. There is an EXCEL spreadsheet used to generate the developed data that is available in DTN: GS000208311221.001, and an identical spreadsheet formatted to display the formulas that can be printed out as hard copies.

Mod3-ppt1.xls: EXCEL spreadsheet used to perform calculations for developing mod3-ppt.dat, with values in cells shown.

Mod3-ppt2.xls: EXCEL spreadsheet used to perform calculations for developing mod3-ppt.dat, with formulas in cells shown.

c. Spreadsheet calculations

Calculations in the spreadsheet MOD3-PPT.xls are done following a series of steps outlined in the first sheet of the file, and reiterated here.

Step 1: average daily precipitation is calculated for USGS weather stations WX1 and WX3 for the period July 17, 1987 through September 30, 1994. For gaps in the record, a value of zero is estimated.

Step 2: Average annual precipitation is calculated for the six NTS stations and two NWS stations for all records beginning on July 17, 1987 and ending on September 30, 1994. This period of time coincides with the period for which precipitation data is available for USGS weather stations WX1 and WX3 (either stations). For all eight stations, the ratio $B_i = AAP_o/AAP_i$ is calculated, where AAP_i = average annual precipitation for the period July 17, 1987 – July 30, 1994 for station i, and AAP_o = mean average annual precipitation for USGS weather stations WX1 and WX3 (calculated in step 1), rounded to the nearest millimeter. The ratio is then used to scale the daily precipitation records for all eight stations using $PPT_i * = B_i(PPT_i)$, where B_i is the scaling factor, PPT_i is the original daily precipitation record for station i, and PPT_i is the adjusted daily precipitation record. The scaling function is applied to all eight stations for 1/1/80 through 12/31/94.

Step 3: An inverse-distance-squared interpolation is performed to estimate the mean daily precipitation for WX1 and WX3 for the period July 17, 1987 – July 30, 1994. The inverse distance squared interpolation involves the calculation of a linear weighting factor based on the distance between locations. A central location on Yucca Mountain used with UTM coordinates of 548,553 m easting, 4,078,230 m northing. The equation is:

Weighting factori = (1/di2)/(Σi (1/(di i2))

where d_i is the distance of station i from the central location having the indicated coordinates. Station coordinates, calculated distances, and calculated weighting factors are listed in the spreadsheet.

Step 4: The inverse distance squared model defined in step 3 is used to calculate the daily precipitation for the location defined in step 3.

Step 5: A linear model, based on a regression of measured precipitation vs. the adjusted daily precipitation record (the inverse-distance-squared interpolated precipitation), is applied to the results of the inverse-distance-squared interpolation for the period January 1, 1980 through September 30, 1994 using:

$$PPT_{YM} = 0.946546 * ([(1/d_i^2)/\Sigma_i (1/(d_i^2))] PPT_i^*)+0.0821$$

where PPT_{YM} is the estimated daily precipitation amount (to the nearest millimeter only) for the central location defined by the coordinates in step 3, and PPT_i^* is the scaled daily precipitation amount for station i. The results of the linear model are used to define the Yucca Mountain daily precipitation estimates for January 1, 1980 through May 11, 1989 (file mod3-ppt.day). The results of step 1 (to the nearest millimeter only) are used to define the Yucca Mountain daily precipitation estimates for May 11, 1989 through October 1, 1995 (file mod3-ppt.dat).

Example of developed data precipitation record for Yucca Mountain that was used directly as input for INFIL V2.0. (data source: GS000208311221.001)

Year	Day of Year	Daily Precip-itation (mm)	Year	Day of Year	Daily Precip-itation (mm)	Year	Day of Year r	Daily Precip-itation (mm)	Year	Day of Year	Daily Precip-itation (mm)	Year	Day of Year	Daily Precip-itation (mm)
80	1	0	80	74	0	80	147	0	80	220	0	80	293	0
80	2	0	80	75	0	80	148	0	80	221	0	80	294	0
80	3	0	80	76	0	80	149	0	80	222	0	80	295	0
80	4	0	80	77	0	80	150	0	80	223	0	80	296	0
80	5	0	80	78	0	80	151	0	80	224	0	80	297	0
80	6	0	80	79	0	80	152	0	80	225	0	80	298	0
80	7	0	80	80	0	80	153	0	80	226	0	80	299	0

2. Development of Daily Climate Input Using Daily09 V1.0

a. Name of routine/macro with version/OS/hardware environment and user information:

Name of software routine: DAILY09 V1.0
OS and hardware environment: Windows NT 4.0, Pentium Pro PC
Computer Identification: SM321276 with a USGS specific host-name P720dcasr
Software Users: Joseph Hevesi (916-278-3274), Alan Flint (916-278-3221)
User Location: U.S. Geological Survey, Room 5000E, Placer Hall, 6000 J Street, Sacramento, CA 95819-6129

b. Name of commercial software with version/OS/hardware used to develop routine/macro:

The source code for DAILY09 V1.0 was developed using the standard FORTRAN77 programming language. The source code was written, debugged, and compiled (for PC platforms using INTEL processors) using DIGITAL Visual Fortran with Microsoft Developer Studio, v. 5.0.

c. General Description of routine/macro:

DAILY09 V1.0 is a FORTRAN77 routine developed in accordance with AP-SI.1Q, specifically for the analysis/model activity documented in this VTR. The routine source code (DAILY09.FOR), compiled executable file (DAILY09.EXE), routine control file (DAILY09.CTL), input and output files used for routine validation, supplemental files created as part of validation testing, and a copy of this attachment, are located under the directory DAILY09 on a CD-ROM labeled DAYINPUT-1. The routine source code, control file, and the input and output files are ASCII text files that can be read using any standard ASCII text editor and can be imported into standard word processing applications such as Microsoft

Word. The executable file can be used to run DAILY09 V1.0 on any PC with an INTEL processor (with adequate RAM).

- The following electronic files including DAILY09 V1.0 and selected analog input and output files are provided:

DAILY09.CTL:	input file consisting of the input and output file names for BLOCKR7, along with parameters needed to perform the 36 blocking ridge angle calculations.
DAILY09.FOR:	FORTRAN source code listing for the routine BLOCKR7. A printout of the source code is included as part of this attachment.
DAILY09.EXE:	Executable file for the routine BLOCKR7, compiled for INTEL processors.
ROSALIA.DAT:	ASCII text file exported from the EARTHINFO NOAA daily climate records WEST2 database. This file is the input file to DAILY09 V1.0.
ROSALIA.DAY:	Auxiliary output file created by DAILY09 V1.0. The file contains all daily climate data provided by ROSALIA.DAT and is used to test for the proper re-formatting. The calculated average daily air temperature is included. This file is used only as part of the validation test for DAILY09.
ROSALIA.INP:	Primary output file created by DAILY09 V1.0. This file is used directly as input to INFIL V2.0 for defining the daily climate input parameters needed for simulating net infiltration.

d. Supporting Information

- Procedure for running routine:
  To run the routine DAILY09, an executable version of the code and all input files must be placed in the same directory. The routine is executed by typing DAILY09 in a DOS window or by double clicking on the file DAILY09.EXE in Windows NT. The input and output file names and the parameters used for the blocking ridge calculations must be in the correct sequential order as specified in the routine control file DAILY09.CTL (see example listing in this section)

- Example listing of ROSALIA.DAT.
  This ASCII file is exported from EARTHINFO using the NCDC export format option. The data shown in this subset is for maximum daily air temperature (TMAX), followed by precipitation (PRCP), with the record starting in May (5) of 1948, continuing through November (11) of 1948. On the first 2 monthly records it is noted just above the top line how to read the file. Month 5 has no data (-99999) for temperature, month 6 has data in degrees Fahrenheit. (See next page.)

- Example listing of ROSALIA.DAT (from previous page)

```
                    Tmax    1948  5 (May)      1 (Day)          2 (Day)          3 (Day)
DLY45718002TMAX F19480599990310198-99999M10298-99999M10398-99999M10498-
99999M10598-99999M10698-99999M10798-99999M10898-99999M10998-99999M11098-
99999M11198-99999M11298-99999M11398-99999M11498-99999M11598-99999M11698-
99999M11798-99999M11898-99999M11998-99999M12098-99999M12198-99999M12298-
99999M12398-99999M12498-99999M12598-99999M12698-99999M12798-99999M12898-
99999M12998-99999M13098-99999M13198-99999M1
```

Tmax 1948 6 (June) 1 77 (F) 2 81 (F) 3 67 (F)
DLY45718002TMAX F19480699990310198 00077 10298 00081 10398 00067 10498 00066 10598
00079 10698 00084 10798 00088 10898 00086 10998 00087 11098 00077 11198 00069 11298 00074
11398 00071 11498 00076 11598 00071 11698 00066 11798 00069 11898 00073 11998 00077 12098
00065 12198 00061 12298 00069 12398 00075 12498 00069 12598 00077 12698 00077 12798 00081
12898 00086 12998 00091 13098 00083 13198-99999M1

DLY45718002PRCPHI19480599990310198-99999M10298-99999M10398-99999M10498-
99999M10598-99999M10698-99999M10798-99999M10898-99999M10998-99999M11098-
99999M11198-99999M11298-99999M11398-99999M11498-99999M11598-99999M11698-
99999M11798-99999M11898-99999M11998-99999M12098-99999M12198-99999M12298-
99999M12398-99999M12498-99999M12598-99999M12698-99999M12798-99999M12898-
99999M12998-99999M13098-99999M13198-99999M1

DLY45718002PRCPHI19480699990310198 00000 10298 00000 10398 00000 10498 00017 10598
00001 10698 00000 10798 00000 10898 00000 10998 00000 11098 00040 11198 00000 11298 00057
11398 00005 11498 00002 11598 00000 11698 00046 11798 00012 11898 00000 11998 00000 12098
00000 12198 00034 12298 00005 12398 00004 12498 00000 12598 00005 12698 00005 12798 00000
12898 00000 12998 00000 13098 00002 13198-99999M1

- Example listing of ROSALIA.DAY. DAILY09 uses the EARTHINO data to reformat into *.DAY format prior to identification of gaps, conversions and averaging. When compared to the above EARTHINFO file it indicates that the reformatting done in DAILY09 is correct. This file also includes the conversion of air temperature from Fahrenheit to Celsius. June 1, 1948 in the EARTHINFO file above is 77 (F), June 2 is 81 (F). In file below the conversion results in June 1 = 25(C) and June 2 = 27.2(C), calculated as degrees C = (degrees F – 32) * (5/9).

Output file generated using program DAILY09.FOR
Output file = Rosalia.day
Daily climate record for Rosalia, Washington
GU1 Upper bound glacial transition climate analog (4/12/1999)

- Example listing of ROSALIA.DAY. (continued)

Station ID = 457180

Dy = day
Mo = month
Yr = year
Max = maximum
Min = minimum
Precip = total daily precipitation
Temp = daily air temperature
mm = millimeters
deg C = degrees Celsius

Data Flags:

-999.9 = missing data value
M = missing data flag
A = accumulated measurement (multiple days)
T = trace amount (less than measurement resolution)

Record Day No.	Year	Mo	Day of Mo	Day of Yr	Precip mm	Max Temp deg C	Min Temp deg C	Snow Fall mm
54177	1948	5	1	122	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54178	1948	5	2	123	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54179	1948	5	3	124	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54180	1948	5	4	125	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54181	1948	5	5	126	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54182	1948	5	6	127	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54183	1948	5	7	128	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54184	1948	5	8	129	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54185	1948	5	9	130	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54186	1948	5	10	131	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54187	1948	5	11	132	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54188	1948	5	12	133	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54189	1948	5	13	134	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54190	1948	5	14	135	-999.9 M	-999.9 M	-999.9 M	-999.9 M

- Example listing of ROSALIA.DAY. DAILY09 uses the EARTHINO data to reformat into *.DAY format prior to identification of gaps and averaging, but following conversion from Fahrenheit to Celsius. The file below is precipitation for 1971 (Dec), 1972 (all) and 1973 (Jan and Feb only), following the reformatting and conversion to Celsius. The year 1972 has large gaps and when compared to the final input file will be omitted.

Output file generated using program DAILY09.FOR
Output file = Rosalia.day
Daily climate record for Rosalia, Washington
GU1 Upper bound glacial transition climate analog (4/12/1999)

Station ID = 457180

Dy = day
Mo = month
Yr = year
Max = maximum
Min = minimum
Precip = total daily precipitation
Temp = daily air temperature
mm = millimeters
deg C = degrees Celsius

Data Flags:

-999.9 = missing data value
M = missing data flag
A = accumulated measurement (multiple days)
T = trace amount (less than measurement resolution)

Record Day Number	Year	Mo	Dy of Mo	Dy of Yr	Precip mm	Max Temp deg C	Min Temp deg C	Snow Fall mm
62791	1971	12	1	335	0.0	1.1	-3.9	0.0
62792	1971	12	2	336	0.0	3.9	-2.8	0.0
62793	1971	12	3	337	0.0 T	2.8	-4.4	0.0 T
62794	1971	12	4	338	0.0	1.7	-6.1	0.0
62795	1971	12	5	339	5.1	2.2	-1.7	63.5
62796	1971	12	6	340	0.0	2.8	-5.0	0.0
62797	1971	12	7	341	0.0	-2.8	-16.1	0.0
62798	1971	12	8	342	0.0	-6.7	-15.6	0.0
62799	1971	12	9	343	0.0	2.8	-7.8	0.0
62800	1971	12	10	344	0.0	2.2	-2.2	0.0
62801	1971	12	11	345	7.6	0.0	-8.9	50.8
62802	1971	12	12	346	2.0	1.1	-8.9	25.4

- Example listing of ROSALIA.INP. This is the main output file from DAILY09 V1.0, generated using the exported EARTHINFO record for Rosalia, WA. The file is used directly as input to INFIL V2.0. The file includes 1971 and 1973. As the data from the entire month of June in 1972 was missing in the above file, it is omitted from the final file indicated below. This verifies the omission of years when the gap identified is large (> 10 days for precipitation and > 20 for air temperature). In addition, the following file illustrates the additional column of mean air temperature calculated as (TMAX+TMIN)/2.

Output file generated using program DAILY09.FOR
Output file = Rosalia.inp
Daily climate record for Rosalia, Washington
GU1 Upper bound glacial transition climate analog (4/12/1999)

Station ID = 457180

Dy = day
Mo = month
Yr = year
Max = maximum
Min = minimum
Precip = total daily precipitation
Temp = daily air temperature
mm = millimeters
deg C = degrees Celsius

Data Flags:

-999.9 = missing data
M = missing data flag
A = accumulated measurement (multiple days)
T = trace amount (less than measurement resolution)
C1 = calculated value (type 1 calculation)
E1 = estimated value (type 1 estimation)
E2 = estimated value (type 2 estimation)
E3 = estimated value (type 3 estimation)

Record Day Number	Year	Mo	Dy of Mo	Dy of Yr	Precip mm	Max Temp deg C	Min Temp deg C	Mean Temp deg C	Snow Fall mm
62791	1971	12	1	335	0.0	1.1	-3.9	-1.4 C1	0.0
62792	1971	12	2	336	0.0	3.9	-2.8	0.6 C1	0.0
62793	1971	12	3	337	0.0 T	2.8	-4.4	-0.8 C1	0.0 T
62794	1971	12	4	338	0.0	1.7	-6.1	-2.2 C1	0.0
62795	1971	12	5	339	5.1	2.2	-1.7	0.3 C1	63.5
62796	1971	12	6	340	0.0	2.8	-5.0	-1.1 C1	0.0

- Example listing of ROSALIA.DAY indicating small gaps in precipitation and air temperature data.

Output file generated using program DAILY09.FOR
Output file = Rosalia.day
Daily climate record for Rosalia, Washington
GU1 Upper bound glacial transition climate analog (4/12/1999)

Station ID = 457180

Dy = day
Mo = month
Yr = year
Max = maximum
Min = minimum
Precip = total daily precipitation
Temp = daily air temperature
mm = millimeters
deg C = degrees Celsius

Data Flags:

-999.9 = missing data value
M = missing data flag
A = accumulated measurement (multiple days)
T = trace amount (less than measurement resolution)

Record Day Number	Year	Mo	Dy of Mo	Dy of Yr	Precip mm	Max Temp Deg C	Min Temp Deg C	Snow Fall mm
71263	1995	2	10	41	0.0	8.3	-1.7	0.0
71264	1995	2	11	42,	0.0	6.1	-2.8	0.0
71265	1995	2	12	43	0.0	1.1	-8.9	0.0
71266	1995	2	13	44	-999.9 M	-6.7	-12.2	-999.9 M
71267	1995	2	14	45	0.8	-7.2	-12.2	12.7
71268	1995	2	15	46	0.0	-6.7	-11.7	0.0
71269	1995	2	16	47	3.8	2.2	-999.9 M	50.8
71270	1995	2	17	48	13.7	4.4	0.0	0.0
71271	1995	2	18	49	0.0	7.8	1.1	0.0
71272	1995	2	19	50	8.9	11.1	2.8	0.0
71273	1995	2	20	51	5.8	13.3	8.3	0.0

- Example listing of ROSALIA.INP illustrating that the gap in precipitation is replaced by a zero, and the gap in air temperature is replaced with a linear interpolation between the numbers on either side of the gap.

Output file generated using program DAILY09.FOR
Output file = Rosalia.inp
Daily climate record for Rosalia, Washington
GU1 Upper bound glacial transition climate analog (4/12/1999)

Station ID = 457180

Dy = day
Mo = month
Yr = year
Max = maximum
Min = minimum
Precip = total daily precipitation
Temp = daily air temperature
mm = millimeters
deg C = degrees Celsius

Data Flags:

-999.9 = missing data
M = missing data flag
A = accumulated measurement (multiple days)
T = trace amount (less than measurement resolution)
C1 = calculated value (type 1 calculation)
E1 = estimated value (type 1 estimation)
E2 = estimated value (type 2 estimation)
E3 = estimated value (type 3 estimation)

Record Day Number	Year	Mo	Dy of Mo	Dy of Yr	Precip mm	Max Temp deg C	Min Temp deg C	Mean Temp deg C	Snow Fall mm
71263	1995	2	10	41	0.0	8.3	-1.7	3.3 C1	0.0
71264	1995	2	11	42	0.0	6.1	-2.8	1.7 C1	0.0
71265	1995	2	12	43	0.0	1.1	-8.9	-3.9 C1	0.0
71266	1995	2	13	44	0.0 E1	-6.7	-12.2	-9.4 C1	-999.9 M
71267	1995	2	14	45	0.8	-7.2	-12.2	-9.7 C1	12.7
71268	1995	2	15	46	0.0	-6.7	-11.7	-9.2 C1	0.0
71269	1995	2	16	47	3.8	2.2	-5.8 E2	-1.8 C1	50.8

A listing of the source code for DAILY09 V1.0 is included as Attachment V to USGS (2001).

3. Development of Stochastic Simulation Precipitation Data

The data from sites identified as 4ja and Area 12 that was used to develop 100-year period simulations are from work documented and available through a draft Water Resources Investigation Report that was submitted to records and assigned Accession Number MOL.19970409.0087. The data files were submitted as a surrogate record to this report, and assigned the Accession Number MOL.20000317.0164. The standard statistical software programs MARKOV and PPTSIM used to develop this data are qualified and controlled by the OCRWM Software Configuration Management. The developed data are the Mod3-ppt.dat, Mod3ppt1.xls, Mode3ppt2.xls, and Mod3-ppt.text files listed in the surrogate record submitted on CD ROM. For INFIL V2.0, the file for the stochastic data is named PPTSIM (option 1 for IPPTDAT program variable). A summary of developed daily climate input files used for modern climate scenarios used for the AMR ANL NBS HS-000032 is shown below in Table A1-2.

Table A1-2 PPTSIM AND MARKOV [mm, millimeters] (data source: GS000208311221.001)

	Yucca Mountain calibration daily climate input	4JAstochastic simulation	Area 12 MesaStochastic simulation
Filename	Mod3-ppt.dat	4JA.s01	Area12.s01
Beginning of record	01/01/1980	n/a	n/a
Ending of record	10/01/1995	n/a	n/a
Total number of years for simulation	15.75	100	100
Mean annual precipitation (mm)	181	140	328
Maximum daily precipitation (mm)	58	82	76

APPENDIX I-C: GEOSPATIAL INPUT DATA FOR INFIL V2.0 FY99

Model Grid Geometry and Watershed Modeling Domains for the Yucca Mountain Site

The development of the geospatial input parameter base grid and the separate watershed modeling domains requires the application of Geographic Information Systems (GIS) to transfer available digitized map data, which is in a vector-based format, onto the grid-cell of the raster-based format of the DEM (a process referred to as rasterization). The vector-based map coverages used as input by the net infiltration model include bedrock geology and soil type maps. In addition to the rasterization procedure, GIS applications are also used for calculating slope and aspect as well as latitude and longitude coordinates for all grid cells. Geospatial parameters that are not available as either raster-based or vector-based map coverages are developed using a series of FORTRAN routines documented in USGS (2001), that are applied sequentially. The routines are used to overlay three separate bedrock geology maps (after rasterization), estimate soil thickness, calculate the blocking ridge parameters, calculate surface water flow routing parameters, and extract the watershed model domains.

All acquired and estimated geospatial parameters required as input for INFIL V2.0 are combined into a single ASCII file defining the base-grid for all extracted watershed model grids (DTN: GS000308311221.004). The geospatial parameter input files defining watershed model domains are extracted as separate files from the developed base-grid using the routine WATSHD20 V1. All FORTRAN routines (GEOMAP7 V1.0, GEOMOD4 V1.0, SOILMAP6 V1.0, and BLOCKR7 V1.0) are qualified for use in accordance with OCRWM Procedure AP-SI.1Q, Rev 2. The use of the acquired software application ARCINFO V6.1.2 was exempt. The purpose of these data is to provide spatial information and properties for each grid block necessary to calculate net infiltration at each location for the Yucca Mountain site using the model INFIL V2.0.

A. Spatial Discretization and the Base-Grid

The net infiltration modeling procedure begins with building a geospatial input parameter base grid using the selected digital elevation model (DEM) to define the base-grid geometry. The DEM (DTN: GS000308311221.006), selected for defining the grid geometry is the composite DEM used for the original net infiltration model (Flint et al., 1996) that was developed from two standard USGS 7.5 minute 30-meter DEMs (Busted Butte and Topopah Spring NW). The two DEM's (DTN: GS000200001221.003) were combined into a composite DEM (DTN: GS000308311221.006) by using the ARCINFO GRID module. Within this module a command MERGE is used to perform the combining process. Once the two DEM's are combined, it was necessary to convert the projection coordinates from decimal-degrees into UTM coordinates. This was done using the standard ARCINFO PROJECT command. The grid geometry of the composite DEM (DTN: GS000308311221.006) is based on the Universal Transverse Mercator projection (zone 11, NAD27, DTN: GS000200001221.003) and consists of 691 rows in the north-south direction and 367 columns in the east-west direction covering a rectangular area centered over Yucca Mountain and the potential repository site, with the following corner coordinates:

The DEM (DTN: GS000308311221.006) selected for defining the Yucca Mountain grid geometry is the composite DEM used for the original net infiltration model (Flint et al., 1996) that was developed from two standard USGS 7.5 minute 30-meter DEMs (Busted Butte and Topopah Spring NW). The two DEMs (DTN:GS000200001221.003) were combined into a composite

DEM (DTN: GS000308311221.006) by using the ARCINFO, ARC-EDIT, ARC-PLOT, and ARC-GRID modules, utilizing a series of standard commands within the various modules. The grid geometry of the composite DEM (DTN: GS000308311221.006) is based on the Universal Transverse Mercator (UTM) projection (zone 11, NAD27) and consists of 691 rows in the north-south direction and 367 columns in the east-west direction covering a rectangular area centered over Yucca Mountain and the potential repository site, with the following corner coordinates:

Northwest corner:	544,661 meters easting, 4,087,833 meters northing
Northeast corner:	555,641 meters easting, 4,087,833 meters northing
Southeast corner:	555,641 meters easting, 4,067,133 meters northing
Southwest corner:	544,661 meters easting, 4,067,133 meters northing

The elevation provided by the composite DEM (253,597 values) is the primary geospatial parameter used by the net infiltration model. Elevation is used to define the surface-water flow-routing network, which is in turn used to define modeled separately as closed hydrologic systems. Elevation is used to define slope, aspect, and blocking ridge parameters for modeling incoming solar radiation that is in turn used in an energy balance calculation for modeling potential evapotranspiration. The calculated slope is also used to model soil thickness. Additional uses of elevation values in the net infiltration model include estimation of spatially distributed daily climate input (precipitation and air temperature).

Figure A1-1 is a shaded relief representation of the Yucca Mountain DEM and includes the location of the 1999 UZ flow model boundary, the 1999 design potential repository boundary, and the trace of the main Exploratory Studies Facility drift. Also shown are the locations of the neutron borehole sites used to calibrate the 1996 model as well as provide core samples for measuring bedrock hydraulic conductivity. Figure A1-1 illustrates the level of detail provided by the DEM in terms of representing discrete topographic features by using elevation, which is the primary geospatial-input parameter for the net-infiltration model. The DEM has an average elevation of 1,237 meters, a minimum elevation of 918 meters along the southern perimeter, and a maximum elevation of 1,969 meters along the northern perimeter.

Figure A1-1. Yucca Mountain DEM used to define geospatial-input parameters and watershed modeling domains. (Appendix 3)

DEM elevations in the base grid are used for calculating and estimating geospatial-input parameters and are also used directly as an input in the developed geospatial-parameter input file. Section 6.3.2 discusses the application of elevation directly as an input parameter for INFIL V2.0 calculations, which includes estimating the spatial distribution of precipitation and air temperature. Sections 6.5.2 and 6.5.3 discuss the application of DEM elevations for calculating flow-routing parameters and developing watershed model domains using the routines SORTGRD1 V1.0, and CHNNET16 V1.0. Section 6.4.4 describes the application of DEM elevations for calculating topographic parameters, which include slope, aspect, and blocking ridge angles, using ARCINFO V6.1.2 and the routine BLOCKR7 V1.0.

Development of the Surface Drainage Network

To generate watershed-modeling domains, the surface-water drainage network was defined using the base grid supplied as output from SOILMAP6 V1.0 and GEOMOD4 V1.0. Flow directions were calculated for each grid cell using a 2-step process. For the first step, the entire base grid is sorted by elevation using the routine SORTGRD1 V1.0. In the second step, flow-routing directions are calculated based on a standard D8 routing algorithm (flow is routed to one of eight adjacent grid cells having the lowest elevation) using the routine CHNNET16 V1.0.

CHNNET16 V1.0 is a convergent flow routing algorithm; multiple cells are allowed to route to a single cell, but any given cell can route to only one downstream grid cell (as opposed to two in cases of flow dispersion). The CHNNET16 V1.0 algorithm provides a method for routing through surface depressions in the DEM, which were found to be numerous. The surface depressions are in part a characteristic of poorly established drainage networks across alluvial fans and basins in arid and semiarid environments. Surface depressions are also caused by inaccuracy in the DEM in terms of both elevation values and grid resolution. If the DEM grid is too coarse relative to channel dimensions it cannot accurately capture the natural channel, and this problem tends to be most severe on broad alluvial fans and basins as opposed to upland areas where the drainage network is more accurately defined by the rugged terrain. The CHNNET16 V1.0 routing algorithm allows DEM surface depressions of up to 20 layers deep (20 grid cells need to be crossed before surface flow escapes the depression), and this was found to be greater than the largest depression encountered in the Yucca Mountain DEM. In addition to the flow routing parameters, output from CHNNET16 V1.0 includes a flow accumulation term, which indicates the number of upstream cells for each grid cell in the initial model grid.

Development of Watershed Model Domains

Division of the net-infiltration model domain into a set of smaller, isolated watershed model domains was needed to decrease simulation run-times for INFIL V2.0 by allowing the simulation to be distributed over multiple computer processors. The isolated watershed domains allow for a more efficient analysis of the impact of watershed characteristics on simulation results. Additionally, the smaller, closed modeling systems enable a more efficient mass balance checking because each model domain is a single watershed with only one outflow location.

To develop a composite watershed-modeling domain consisting of all watersheds either overlying or immediately adjacent to the area of the site-scale UZ flow and transport model, the boundary of the UZ model was overlain on the numerically defined drainage networks obtained from CHNNET16 V1.0. The outflow cell (the discharge point for all upstream grid cells) of each major drainage network affecting the UZ model area was identified using TRANSFORM for a visual analysis of the flow accumulation map (Figure A1-2). A total of 10 separate watershed model grids were extracted using the routine WATSHD20 V1.0, which executes a reverse flow-routing algorithm to identify all model cells upstream from the selected outflow cell. The model grid defining the extracted watershed domain includes the active grid cells upstream from the outflow cell and also an outer perimeter layer of inactive cells that are needed as boundary cells during surface-water flow routing. The perimeter cells are also used in the mass-balance checking calculation performed using Equation 6-13 to ensure that outflow is consistent with the cumulative mass balance calculated for all grid cells in the watershed model domain.

Whether or not the calculated flow divides accurately represent the natural system depends on the resolution and accuracy of the DEM, and the accuracy of the flow routing algorithm in capturing the true channel network. An assumption was made that the accuracy of the DEM and the accuracy of the D8 flow routing algorithm was adequate for the purpose of this modeling activity. This assumption was based in part on the knowledge that the model results would be interpolated onto the coarser mesh of the UZ flow and transport model. The assumption was also based on the knowledge that a static DEM was being used to represent topography for the next 10,000 years. In other words, an accurate representation of the present-day channel network at Yucca Mountain is considered to be irrelevant given that the active channel network is likely to change significantly over a 10,000-year period, particularly if wetter climates develop.

Figure A1-2. Isolation of the drainage networks overlying the area of the UZ flow and transport model. (Appendix 3)

The main watersheds included in the composite watershed model area are Yucca Wash, Drill Hole Wash, Dune Wash, Solitario Canyon #1, and Plug Hill[2]. Additional drainages that were included in the composite model to provide a buffer zone along the western edge of the UZ model are Jet Ridge #1, Jet Ridge #2, Jet Ridge #3, Solitario Canyon #2, and Solitario Canyon #4. The watershed model domains were restricted to the western side of the Fortymile Wash channel because the Yucca Mountain DEM captures only a small part of the lower Fortymile Wash drainage, and complete watersheds cannot be defined for most sections of the DEM east of Fortymile Wash. With the exception of Yucca Wash, and Jet Ridge #1, all watersheds are fully defined by the DEM. For Yucca Wash, northern sections of the watershed are missing because the DEM does not extend far enough north (the northern perimeter of the watershed is defined by the DEM boundary). The missing area is small relative to the total watershed area, and the only potential impact occurs in the Yucca Wash channel along the northeastern perimeter of the UZ flow and transport model area. For Jet Ridge #1, the lowermost segment of the eastern perimeter is defined by the DEM boundary. The missing eastern section of Jet Ridge #1 is an insignificant area that does not affect results obtained for the UZ flow and transport model area.

B. Geospatial Data File

The site location and attribute file contains 19 columns of numbers: location easing (m), slope (degrees), aspect (degrees), elevation (m), latitude (decimal degrees), longitude (decimal degrees), soil type, soil depth class, underlying geologic, geomorphic position and the elevation angle (degrees) of the surrounding topography every identification (unitless), Universal Transverse Mercater (UTM) nothing (m), UTM 10 degrees beginning at 10 degrees with east being 90 degree, south being 180 degrees, west being 270 degrees and north being 360 degrees. In the current version of INFIL, geomorphic position is a place holder for identifying sites located in channels.

Geospatial Input Variable Order:

```
100  read(8,*,end=130) locid(n),easting(n),northing(n),lat(n),lon(n),
   1                   row(n),col(n),iwat(n),totoutc,elev(row(n),col(n)),

   3      sl(n),asp(n),soiltype(n),

   4      dclass,depth(n),rocktype(n),topoid(n),vegt,vegc(n),
   5      (ridge(n,j), j=1,36)
```

[2]The names selected for the extracted watershed modeling domains are not necessarily the established geographic names for these physiographic features. They are used here only as a means of identifying the separate watershed models.

Input Variables

Source data software used for development of geospatial input data are as follows:

Elevation, northing and easting: USGS Digital Elevation Model (DEM) from Topopah Spring West and Busted Butte 7.5-minute quadrangles: DTN: GS000308311221.006, ARCINFO, to produce ASCII file 30MSITE.INP (DTN: GS000308311221.006)

Downstream grid cell: 30MSITE.INP, SORTGRD1 V1.0, CHNNET16 V1.0 (DTN: GS000308311221.006)

Number of upstream cells: 30MSITE.INP, SORTGRD1 V1.0, CHNNET16 V1.0 (DTN: GS000308311221.006)

Slope: 30MSITE.INP, ARCINFO (DTN: GS000308311221.006)

Aspect: 30MSITE.INP, ARCINFO (DTN: GS000308311221.006)

Soil-type: INFIL V2.0 control file INFILS5o.CTL and 30MSITE.INF (DTN: GS960508312212.007, GS000308311221.006)

Soil depth class: soil depth map (DTN: GS960508312212.007), INFIL V2.0 control file INFILS5o.CTL, and 30MSITE.INP (DTN: GS000308311221.006)

Modeled soil depth: soil depth class (DTN: GS960508312212.007), GEOMAP7 V1.0, GEOMOD4 V1.0, and SOILMAP6 V1.0

Rock type: INFIL V2.0 control file INFILS5o.CTL, and README2.DAY [coverage explanations for Day et al. (1998)], (DTN: GS971208314221.003)

Topographic position: INFIL V2.0 control file INFILS5o.CTL

Blocking ridges: 30MSITE.INP (DTN: GS000308311221.006), BLOCKR7 V1.0

Data Set

The data set consists of three parts.

Part 1: Geospatial input for each of 10 drainages

Part one of the data set is a set of 10 files consisting of grid blocks within individual watershed modeling domains and all associated geospatial input listed above. These files are in EXCEL worksheets formatted with descriptive column headers and are available in DTN: GS000308311221.004:

YuccaWash.xls	Solitario4.xls
DuneWash.xls	PlugHill.xls
DrillHole.xls	JetRidge1.xls
Solitario1.xls	JetRidge2.xls
Solitario2.xls	JetRidge3.xls.

The parameters included in each file are grid cell identifier number, UTM easting, UTM northing (m), latitude, longitude (decimal degrees), grid cell row index, grid cell column index, downstream grid cell identifier (used for surface water routing), number of upstream grid cells, elevation (m), slope (degrees inclination from horizontal), aspect (degrees from north), soil-type identifier, soil depth class identifier, modeled soil depth (m), rock-type identifier, topographic position, vegetative type, vegetative cover, 36 blocking ridge angles (decimal degrees, inclination above horizontal) (see Table A1-3). An abbreviated example of the files is shown in Table A1-4.

This input is primarily based on the USGS Digital Elevation Model (DEM) from Topopah Spring West and Busted Butte 7.5-minute quadrangles. The base grid (DTN: GS000308311221.006) was used to define location coordinates for the geospatial parameter input files for the 1996 version of the net infiltration model (Flint et al., 1996). The DEM is a regular 2-dimensional grid of 253,597 cells having dimensions of 30 x 30 meters and elevations to the nearest meter. The 30-meter grid is based on a Universal Transverse Mercator (UTM), zone 11, NAD 1927 projection, consists of 691 northing "rows" (grid cell row index) and 367 easting "columns" (grid cell column index) aligned orthogonal to the UTM coordinate axis, and has a lower left corner coordinate of 544,661 meters easting and 4,067,133 meters northing. Grid locations are also defined using geographic coordinates, latitude and longitude in decimal degrees, which were calculated in ARCINFO and used as input for the SOLRAD sub-model in INFIL V2.0. The row and column location indices are used in the flow routing module in INFIL in the calculation of the surface water run-on term.

Downstream grid cell identifier is the flow routing parameter and determines which of eight surrounding grid cells is the lowest in elevation. A value of –3 indicates the downstream grid cell is a drainage boundary. Flow directions were calculated for each grid cell using a two-step process. For the first step, the entire base-grid is sorted by elevation using the routine SORTGRD V1.0. In the second step, flow routing directions are calculated based on a standard D8 routing algorithm using the routine CHNNET16 V1.0. CHNNET16 V1.0 is a convergent flow routing algorithm; multiple cells are allowed to route to a single cell, but any given cell can route to only one downstream grid cell (as opposed to two in cases of flow dispersion). The CHNNET16 V1.0 algorithm provides a method for routing through surface depressions in the DEM. The number of upstream grid cells is included in each file.

Elevation from mean sea level in meters is included in each file.

Slope is a required input parameter for estimating soil depths. Slope and aspect were calculated for the net infiltration model from the DEM (DTN: GS000308311221.006) using standard GIS applications in ARCINFO.

Soil type is indicated by values of between 1 and 10 (Flint et al., 1996, Table 3, DTN: GS960908312211.003). When encountered in INFIL it uses a lookup table (INFILS5o.CTL) that has all hydrologic parameters for each soil type as listed in Flint et al. (1996). Depth class identifier is a value between 1 and 6 and is used in the preprocessing routine SOILMAP6 V1.0 with depth to bedrock map (DTN: GS960508312212.007, Estimated distribution of geomorphic surfaces and depth to bedrock for the southern half of the Topopah Spring NW 7.5 minute quadrangle and the entire Busted Butte 7.5 minute quadrangle), and slope to calculate soil depth at all grid block locations. Soil depth is estimated using a combination of the soil depth class map and an estimated linear relation between soil depth and slope within each depth class (GEOMAP7 V1.0 and GEOMOD4 V1.0). Soil depth classes represent different ranges in actual soil depths that were estimated using a combination of Quaternary geologic maps, field observations, and soil depth recorded at borehole sites (Flint and Flint, 1995, Table 2). Depth class #1 identifies locations with soil depths ranging from 0 to 0.5 meters and primarily occurs in rugged upland areas. Depth class #2 identifies deeper soils ranging from 0.5 to 3.0 meters occurring at mid to lower side-slope locations in upland areas affected by slumps, slides, and other mass-wasting processes. Depth class #3 identifies locations in the transition zone between upland areas and alluvial fans or basins with intermediate soil depths ranging from 3 to 6 meters. Depth class #4 identifies deep soils with depths of 6 meters or greater. Depth class #5 is an intermediate depth zone equivalent to Depth class #3, however #3 did not represent field conditions well when the Day et al. (1998) map was incorporated into the model. Depth class #5 is therefore an adjusted version of Depth class #3 where the geology is represented by Day et al. (1998) . Depth class #6 occurs where Scott and Bonk (1984) mapped bedrock and Day et al. (1998) mapped deep alluvium. A compromise for this depth class was chosen as 3-6 m. The soil depth classes were used to estimate soil depths based on calculated slope and an empirical soil-depth model (modeled soil depth, in meters). This model is based on an assumed soil depth – slope correlation within the soil depth classes defined for the 1996 version of the net infiltration model (Flint et al., 1996). The conceptual soil depth model for depth class 1 assumes that soils are thinnest at summit and ridge-crest areas as well as steep side slopes. Deeper soils are assumed to occur at the relatively gently sloping shoulder areas that define the transition between summit or ridge crest areas and steep side slope areas. Deeper soils are also assumed to occur for more gently sloping foot-slope locations. The model for soil depth class 1 is defined by:

$$D = 0.03 * S + 0.1, \quad S \leq 10$$
$$D = 0.013 * (10 - S) + 0.4, \quad 10 < S < 40$$
$$D = 0.01, \quad S \geq 40$$

where D = soil depth (in meters), and S = slope (degrees). The model for depth class #2 is defined by:

$$D = 2 - (0.05 * S), \quad S < 32$$
$$D = 0.4, \quad S \geq 32$$

and the model for depth class # 3 is defined by:

$$D = 6 - (0.16 * S), \quad S \leq 25$$
$$D = 2.0$$

For depth class #4, soil depth is set to a uniform depth of 6 meters.

Rock-type identifier defines the rock type for each grid cell so that the corresponding bulk bedrock permeability can be found in the look up table shown in Table A1-5. Bedrock geology was defined for each grid element using three ARCINFO map coverages and a vector to raster conversion performed by ARCINFO. The three maps used for the bedrock determinations are the 1:6000 scale Bedrock Geologic Map of the Central block area by Day et al. (1998), the Preliminary Geologic Map of Yucca Mountain by Scott and Bonk (1984), and the Geologic Map of the Topopah Spring Northwest Quadrangle by Sawyer et al. (1995) . Within the UZ flow and transport model area, bedrock geology for the net infiltration model (which is defined as a unique integer identifier for each rock-type in the geospatial parameter input file) is primarily defined by Day et al. (1998). Bedrock geology for the northern and southern perimeter sections of the UZ flow and transport model area is defined by Scott and Bonk (1984). Bedrock geology is represented in the geospatial parameter input file using a unique integer identifier for each rock-type. The identifier is linked to a bulk (field-scale) saturated permeability in the model control file (represented in GeoK.xls). Multiple rock-types can be assigned the same bulk permeability value in the model control file.

Topographic position is indicated by values ranging from 1 to 4, corresponding to the classification ridgetop, sideslope, alluvial terrace, and channel discussed in Section 6.1.2 of USGS (2001. This information was used in INFIL V1.0 to identify channel locations, but as routing is done in version 2.0 this parameter is not used. It is however maintained as a placeholder.

The 36 blocking ridge angles (degrees inclination above horizontal) are calculated at each 10-degree horizontal arc (with the azimuth aligned in the UTM northing direction) for each grid cell using the routine BLOCKR7. Calculations were performed using the DEM as input and a technique for approximating the 10-degree horizontal angles based on grid cell distances. The blocking ridge parameters cannot account for topographic influences outside of the DEM, and thus the blocking ridge effect is only partly accounted for along the perimeter of the DEM.

Part 2: Geologic unit identifier and associated bulk bedrock saturated hydraulic conductivity
The second part of the data set is the lookup table providing properties for each grid. It consists of a spreadsheet called GeoK.xls and consists of rock-type identifier, source, geologic description, hydrogeologic identifier, and bulk bedrock saturated hydraulic conductivity (Table A1-5). The geologic identifier in the first column is a value that allows each grid cell to use this file as a lookup table to identify rock type. The source is the map the rock type was taken from using ARCINFO coverages. The next two columns are geologic descriptions extracted from the sources that, when combined with map location, allow for the interpretation of corresponding lithostratigraphic unit shown in the next column which is represented by nomenclature from Buesch et al. (1996). The determination of corresponding lithostratigraphic unit is typically straightforward based on description. The column with corresponding hydrogeologic unit is based on Flint (1998 Table 1 and DTN: GS000308312231.002) and incorporates data from analyses of samples of most of the rock types for saturated hydraulic conductivity (DTN: GS000308312231.002). Saturated hydraulic conductivity (K_s) on individual core samples was determined on subsamples from several boreholes (DTN: GS990408312231.001, GS960808312231.001, GS960808312231.005). Cores were vacuum saturated, and K_s was measured using a steady-state permeameter that forces water through the core at a measured pressure while weighing the outflow over time. K_s was calculated using Darcy's law. Mean values of saturated hydraulic conductivity for each hydrogeologic unit were determined by using a geometric mean calculation (DTN: GS000308312231.002). The bulk bedrock hydraulic conductivity represents the combined matrix and fracture saturated hydraulic conductivity of each rock-type. Bulk bedrock hydraulic conductivity was calculated using measured saturated hydraulic conductivity of fracture fill material. A value of 43.2 mm/day was selected and used as a preliminary value. However, a value of 46.7 mm/day is the average value calculated from all measurements in DTN: GS950708312211.003, Fracture/Fault Properties For Fast Pathways Model; the difference in calculated bulk hydraulic conductivity between these values is insignificant and results in bulk hydraulic conductivities that are less than 1% different. Additional values used to calculate bulk bedrock hydraulic conductivity included an estimate of the percent area occupied by 250 micron fractures (the assumption of this size fracture is discussed in Flint et al., 1996) and the mean saturated hydraulic conductivity of the bedrock matrix for that rock type (Flint, 1998, Table 7; DTN: GS000308312231.002). The percent area occupied by fractures of 250-microns aperture is equal to 250 microns divided by 1,000,000 microns per meter, multiplied by the fracture densities in fractures per meter. The fracture densities for each rock type that were used to calculate the bulk bedrock hydraulic conductivities were estimated from field observations and, subsequently, were corroborated by the fracture density data from boreholes NRG-4, NRG-5, NRG-6, NRG-7, SD-9 and SD-12 reported in Altman et al. (1996, Table 3-6, DTN: SNSAND96081900.000).

For the development of hydrogeologic units, the data originally collected from laboratory measurements on all samples from 31 surface-based boreholes drilled from 1995 through 1997, were analyzed and data were submitted in the following data packages: DTN: GS920508312231.012, GS930108312231.006, GS940408312231.004, GS000408312231.004, GS940508312231.006, GS950408312231.004, GS950408312231.005, GS951108312231.009, GS951108312231.011, GS951108312231.010, GS950308312231.002, GS960808312231.004, GS960808312231.001, GS950608312231.008, GS960808312231.005, GS960808312231.003, GS000308312231.001, GS000308312231.002, GS990408312231.001, GS000408312231.003, GS000508312231.005, and GS000508312231.006.

Outliers and inappropriate data have been removed to allow for a better representation of the hydrogeologic units. Physical properties of bulk density, porosity, and particle density; flow properties of saturated hydraulic conductivity and moisture-retention characteristics; and the state variables (variables describing the current state of field conditions) of saturation and water potential were determined for each unit. Units were defined using the data base of physical and hydrologic properties, described lithostratigraphic boundaries and corresponding relations to porosity, recognition of transition zones with pronounced changes in properties over short vertical distances, characterization of the influence of mineral alteration on hydrologic properties such as permeability and moisture-retention characteristics, and a statistical analysis to evaluate where boundaries should be adjusted to minimize the variance within layers.

Part 3: Properties for 10 soil units

The properties in Table A1-6 represent soils located around Yucca Mountain, Nevada. These are measured and calculated properties. Measured properties are bulk density, porosity, and rock fragment content. Saturated hydraulic conductivity, moisture retention curve fit parameters alpha and n, water content at –0.1 bar water potential, and water content at –60 bars water potential were estimated using empirical equations from Campbell (1985). Bulk density, porosity, and rock fragment content were measured using laboratory analyses described in Flint and others (1996, p. 41). The source data for these measured properties were submitted under the following DTNs:

GS950708312211.002 - "FY94 and FY95 Laboratory Measurements of Physical Properties of Surficial Materials at Yucca Mountain, Nevada."

GS960108312211.001 - "FY95 Lab Measurements of Physical Properties of Surficial Material, at Yucca Mountain, NV PART II"

GS960108312211.002 - "Gravimetric and Volumetric Water Content and Rock Fragment Content of 31 Selected Sites at Yucca Mountain, NV: FY95 Laboratory Measurements of Physical Properties of Surficial Material at Yucca Mountain, Part III"

Field and laboratory analyses were conducted on the soils around Yucca Mountain. Large-volume, field bulk-density samples were collected from the surface to 0.3 m by using an irregular-hole, bulk-density device called a bead cone. Bulk density, porosity, rock fragment content, and sand, silt, and clay percentages were determined. Saturated hydraulic conductivity was measured using a double-ring infiltrometer on soils in locations where it could be measured and then compared to conductivity simulated using textural data for the fine-soil fraction (<2 mm) by using Equation 6.12 of Campbell (1985). Log-log water-characteristic curves were determined using Equations 2.15, 2.16, 2.17, 2.18, 5.10, and 5.11 of Campbell (1985) and were converted to van Genuchten curves in Excel. Soil-water contents at -0.1 bar and -60 bars water potential were used as field capacity and residual water content, the difference of which is plant available water content. The soil properties are summarized in Table

A1-6, where the parameters defining the van Genuchten curves (conductivity, alpha, and n) are simulated from texture, rock fragment content, and bulk density measured in the field. Also listed in Table A1-6 are the soil-water contents corresponding to -0.1 and -60 bars water potential for each soil type, calculated using the fitted water-retention van Genuchten curve for each soil type.

To test the validity of using textural analysis as a surrogate for measurements of soil properties, field-measured hydraulic conductivities were compared with the geometric-mean particle diameter using a method discussed in Campbell (1985, eq. 2.15) and with the model predictions of hydraulic properties made using Campbell (1985, eqs. 5.10 and 5.11), which is developed for <2-mm particle sizes. The results indicated an adequate correlation to use textural data for particle sizes < 0.3 mm; however, the presence of rock fragments has a substantial effect on soil properties. To account for the presence of rock fragments, the log of simulated hydraulic conductivity from Campbell (1985) and the gravimetric rock-fragment content were regressed against the log of the measured values of hydraulic conductivity to produce a modified Campbell equation with an r^2 of 0.85. The equation was then applied to each unit in Table A1-6 to determine the saturated hydraulic conductivity. This analysis assumes that textural changes with depth are insignificant and that properties determined from textural sampling from the top 0.3 m of soil represents the entire soil profile. A large percentage of the surficial deposits in the study area are < 0.5 m deep (Flint et al., 1996, Figure 13) and the application of these data for these shallow soils is considered appropriate.

Textural data also were used for the calculation of moisture-retention curves for the surficial soils using Campbell (1985). Six moisture-retention curves were measured in the laboratory on soil units 1, 2, and 4 using tempe cells, pressure pots, and chilled-mirror psychrometers to measure water potential over a full range of saturations (Flint et al., 1996, Figures 16A, 16B, and 16C). Curves were fit to the combined data sets for each soil unit. Curves calculated from the average textural data for the soil units are very similar to the curves from the measured data for the three units. It was considered, therefore, that texture could be used to calculate curves and associated parameters for the remaining five soil units, and all curves are illustrated in Flint et al. (1996, Figure 16D). These parameters are those listed in Table A1-6.

Table A1-3. Description of columns in output files with geospatial input for INFIL V2.0.

Column	Description
1	Grid cell identifier number
2	UTM easting (m)
3	UTM northing (m)
4	Latitude (decimal degrees)
5	Longitude (decimal degrees)
6	Grid cell row index
7	Grid cell column index
8	Downstream grid cell identifier number (used for surface water routing)
9	Number of upstream grid cells
10	Elevation (m)
11	Slope (degrees inclination from horizontal)
12	Aspect (degrees azimuth from the UTM northing axis, in the horizontal plane)
13	Soil type identifier

Column	Description
14	Depth class identifier
15	Modeled soil depth (m)
16	Rock type identifier
17	Topographic position
18	1st of 36 blocking ridge angles (inclination above horizontal, decimal degrees)
54	Last of 36 blocking ridge angles

Table A1-4. Example of output found in files used as geospatial input for INFIL V2.0. (DTN: GS000308311221.004)

Grid cell identifier	UTM Easting (m)	UTM Northing (m)	Latitude (degrees)	Longitude (degrees)	Grid cell row index	Grid cell column index	Downstream grid cell identifier	Number of upstream grid cells	Elevation (m)
59985	545681	4076613	36.8361	116.4877	375	35	-3	0	1393
60288	545681	4076583	36.8359	116.4877	376	35	62707	0	1392
60879	545681	4076553	36.8356	116.4877	377	35	63010	0	1390
61172	545711	4076613	36.8361	116.4874	375	36	-3	0	1389
61179	545681	4076523	36.8353	116.4877	378	35	63573	0	1389
61794	545651	4076613	36.8361	116.488	375	34	-3	0	1387
61795	545711	4076583	36.8359	116.4874	376	36	-3	0	1387
62076	545711	4076553	36.8356	116.4874	377	36	-3	0	1386
62077	545681	4076493	36.835	116.4877	379	35	65103	0	1386
62706	545651	4076583	36.8359	116.488	376	34	-3	1	1384

(Beginning with "Slope", columns continued)

Grid cell identifier	Slope (degrees inclination from horizontal)	Aspect (degrees from northing)	Soil type identifier	Depth class identifier	Modeled soil depth (m)	Rock type identifier	Topographic position	Blocking ridge angle 1	Blocking ridge angle 2
59985	9	197	5	1	0.48	17	4	2	1
60288	9	199	5	1	0.48	17	4	2	1
60879	8	201	5	1	0.46	17	5	2	1
61172	10	109	5	1	0.5	17	4	2	1
61179	8	196	5	1	0.46	17	5	2	1
61794	20	259	5	1	0.33	18	4	3	5
61795	10	108	5	1	0.5	17	4	2	1
62076	10	108	5	1	0.5	17	4	2	1
62077	9	193	5	1	0.48	17	4	2	1
62706	19	259	5	1	0.35	18	4	5	9

Table A1-5. Example from lookup table in INFIL V2.0 providing properties for each grid block, consisting of rock-type identifier, source, geologic description (formation and lithology), corresponding lithostratigraphic unit and hydrogeologic identifier, and estimated fracture density and bulk bedrock saturated hydraulic conductivity based on filled 250-um fractures.[F/m, fractures per meter; mm/d, millimeters per day.] (DTN: GS000308311221.004)

Geologic Identifier	Source	Geologic descriptions from sources		Corres-ponding lithostrati-graphic unit	Corres-ponding hydro-geologic unit	Estimated Fracture density (F/m)	Bulk Bedrock Saturated Hydraulic Conductivity w/filled 250-um fractures (mm/d)
		Formation	Lithology				
2	Scott and Bonk (1984)	Rhyolite of Pinnacles Ridge	Lava flows	Tptrv1	TC	25.0	0.41
3	Scott and Bonk (1984)	Rhyolite of Pinnacles Ridge	Pyroclastic	Tpbt2	BT3	0.5	46.66
4	Scott and Bonk (1984)	Rhyolite of Comb Peak	Lava flows	Tpcpll	CW	7.0	0.09
5	Scott and Bonk (1984)	Rhyolite of Comb Peak	Pyroclastic	Tpbt3	BT3	0.5	46.66
6	Scott and Bonk (1984)	Rhyolite of Vent Pass	Lava flows	Tptrv1	TC	25.0	0.41
7	Scott and Bonk (1984)	Rhyolite of Vent Pass	Pyroclastic	Tpbt3	BT3	0.5	46.66
8	Scott and Bonk (1984)	Rhyolite of Black Glass Canyon	Lava flows	Tpcpll	CW	7.0	0.09
9	Scott and Bonk (1984)	Rhyolite of Black Glass Canyon	Pyroclastic	Tpbt3	BT3	0.5	46.66
10	Scott and Bonk (1984)	Basalt Dikes of Yucca Mountain	Welded	Tpcplnc	CW	7.0	0.09

Table A1-6. Summary of soil properties used as input for INFIL V2.0.
[m/s, meters per second; Pa, pascals; %, percent; g/cm3, grams per cubic centimeter; ------, not applicable] (DTN: GS000308311221.004)

Soil unit	Saturated hydraulic conductivity (simulated, m/s)	alpha (1/Pa)	n	Porosity (%)	Rock fragments (%)	Bulk Density (g/cm3)	Water content at -0.1 bar water potential (%)	Water content at -60 bars water potential (%)
1	5.6×10^{-6}	0.00052	1.24	36.6	10.5	1.60	24.2	5.4
2	1.2×10^{-5}	0.00062	1.31	31.5	11.6	1.73	17.3	2.3
3	1.3×10^{-5}	0.00066	1.36	32.5	18.7	1.70	16.3	1.7
4	3.8×10^{-5}	0.00087	1.62	28.1	21.9	1.81	7.3	0.2
5	6.7×10^{-6}	0.00056	1.28	33.0	15.2	1.69	20.0	3.5
6	2.7×10^{-5}	0.00074	1.40	33.9	11.7	1.66	15.0	1.1
7	5.6×10^{-6}	0.00055	1.26	37.0	17.1	1.58	23.4	4.6
9	5.7×10^{-6}	0.00055	1.30	32.2	19.1	1.72	18.9	2.8

APPENDIX 2. INSTALLATION AND VALIDATION TEST RESULTS FOR INFIL V2.0

Table A2-1. Installation Test Results for INFILV2.0

Documentation of results of execution of the ITP.

Evaluation Tests	Criteria	Met Criteria	Did Not Meet Criteria	Description of Failure
Pre-Installation Test	hard disk size appropriate	Yes		
	CD-ROM available	Yes		
	File transfer system operational	Yes		
	command prompt available	Yes		
	keyboard input accepted	Yes		
Installation Test	files transferred from CD-ROM to hard disk	Yes		
	3 primary output files are produced when infilv2.exe is executed (ITP, Table 1)	Yes		
	18 secondary files are produced when infilv2.exe is executed (ITP, Table 1)	Yes		
	output file Itest3.out matches Table 2	Yes		

Table A2-2. Validation Test Results for INFILV2.0

Test output files commonly are in Notepad. The author has provided those files, and created EXCEL files for the Notepad files used in validation test cases. Supporting information and calculations are provided as an attachment. Examples of the Model Control File (MCF), Geospatial Input file T1.w20, and output files are provided in the attachment to this appendix. Successful results for the validation test steps are indicated by check marks in the "Pass" column. The complete success of all test steps is verified by the signature of the Validation Tester, Jennifer Curtis, as shown on this page.

Test Case	Criteria Description	VTP Test Step	Pass	Fail
Test 0A: Validation of Mod3-ppt.dat Daily Climate Input Format				
0A.1	On successful execution of the program, the following output files have been created: (1) Test0a.1, Test0a.2, Test0a.3, Test0a.3, Test0a.4, Test0a.5, Test0a.6, Test0a.7, Test0a.8, Test0a.9, Test0a.10, Test0a.11, Test0a.12, Test0a.13, Test0a.14, Test0a.15, and Test0a.16. (2) Test0a.v21, Test0a.v22, Test0a.v23, Test0a.v24, Test0a.v25, and Test0a.v26. (RD requirements 1, 13, 14, 15, 16)	(1) Program output, the yearfile.txt file, verifies this activity; (2) Program output, the Test 0a.v23 verifies this and other output of all "v" files.	✓ ✓	
0A.2	The output in the daily water balance output file Test0a.v21 indicates daily water balance results, with each line of output corresponding to the daily time sequence provided by the input file mod3-ppt.dat. The total number of days indicated by the output in Test0a.v21 is 5753. (RD requirements 1, 7, 8, 13)	Review files Test0a.v21 and mod3-ppt.dat.	✓	
0A.3	The output in Test0a.v21 indicates daily variability in air temperature and potential evapotranspiration, as a function of the day-of-year number for each year of the simulation. (RD requirements 1, 3)	Review file Test0a.v21.	✓	
0A.4	(1) The output in the secondary output file Test0a.v26 indicates variable node elevations, soil type, soil depth, and rock type. The set of model nodes are ordered by elevation, with the highest elevation node listed first and the lowest elevation node listed last. (2) The thickness of the root zone layers for each node are defined as a function of soil depth and input parameters in the model control file, as documented in USGS (2001). (3) The soil and rock properties listed for the root zone layers for each node are consistent with the soil and rock parameters defined in the model control file. (4) The root-zone effective water storage capacity (porosity – wilting point) for all layers at all nodes is dependent on the layer thickness and the soil properties at all nodes. (RD requirements 1, 2, 16)	1.) Review output file to verify. 2.) Verify by review of Section 6.7.1-6.7.3 of the AMR, MCF, and Attachment A2-1, Item 2. 3.) Verify by comparison of MCF and T1w.20 file 4.) Review Infilv2.for file for calculation. See Attachment A2-1, Common parameters and definitions.	✓ ✓ ✓ ✓	
0A.5	The output in the summary output file Test0a.v23 provides a listing of the input and output file names specified in the model control file, along with a listing of annual results for each year simulated and average annual rates for the full simulation period. The total number of years listed in Test0a.v23 is 16. (RD requirements 1, 14)	Review Test0a.v23 file Note: The output file for the Annual mass balance map is inadvertently shown as file test0a.1.; the file should be test0a.v25 for all test sequences.	✓	

[signature] for Jennifer Curtis — April 6, 2001

Signature — Date

Test Case	Criteria Description	VTP Test Step	Pass	Fail
0A.6	(1.) The output in the average annual map file Test0a.v24 corresponds to average annual rates for all water balance terms at all active model nodes defined in the geospatial parameter input file T1.w20. Note: The boundary nodes identified by -3 in the T1.w20 file are not active nodes and are not included in the 0a.v24 file. (2) The format for Test0a.v24 is correct according to input format requirements for the post-processing routine MAPADD20.exe, as documented in USGS (2001). (RD requirement 1, 15)	1.) Review test0a.v24 and T1.w20 files. 2.) Compare Test0a.v24 with Test0d.v24 used as input to input to test with Mapadd20 to ensure comparable format. See Attachment A2-1, Item (4) to confirm successful MAPPADD20 output.	✓ ✓	
0A.7	All Output terms in the average annual map file Test0a.v24 are non-uniform, with the exception of the snowfall, snow-cover, snowmelt, and sublimation terms (these are all 0). (RD requirements 1, 4, 15)	Review test0a.24 file.	✓	
0A.8	(1) The results for the three primary output files (Test0a.v21, Test0a.v23, Test0a.v24) are consistent. For example, the average annual net infiltration rate calculated from the results in the daily output file is equal (to the nearest 0.01 mm) to the spatially averaged net infiltration rate calculated from the average annual map file. (2)The spatial and temporal averages calculated from the results in Test0a.v21 and Test0a.v24 are equal (to the nearest 0.01 mm) to the results provided in the summary output file Test0a.v23 (RD req. 7, 13, 14, 15)	(1) Review output files. (See examples of the calculated averages of parameters in .v24 that confirms comparison with .v23.) (2) Calculate parameter average(s) for year from .v21 and compare (See Attachment A2-1, Item 5)	✓ ✓	
0A.9	The absolute values of the program calculated volume balance terms in the daily output file (mass balance, mass balance 2) do not exceed 1E-8 for any day simulated (RD req. 7, 13)	A hand-calculation check of the results in Test0a.v21 shows that the solutions to both 1 and 2 of the RD have absolute values no greater than 1E-8 for any day simulated	✓	
0A.10	The absolute values of the program calculated volume balance terms in the average annual map file Test0a.v24 (mass-balance, max-balance, mass-balance #2) do not exceed 1E-8 for any model node. (RD req. 7, 15)	Review file.	✓	
0A.11	The absolute value of the program calculated volume balance term in the annual summary file Test0a.v23 (mass-balance) does not exceed 1E-5 for any year simulated (RD requirements 7, 14)	Review file.	✓	
0A.12	(1) For day 5549 of the simulation (day 70 of year 1995) the daily water balance map file Test0a.v22 is consistent with the results in the daily output file Test0a.v21 in terms of precipitation, net infiltration, runoff, and run-on. The average daily precipitation, net infiltration, runoff, and run-on terms in the daily output file must agree (to within 0.0001 mm) with the results calculated using the output from the daily water balance map file. (2) For the results included in the daily water balance map file, the water content of any layer cannot exceed the absolute water storage capacity of that layer (layer porosity times layer thickness). (3) The net infiltration rate at any node cannot exceed the bulk saturated hydraulic conductivity at the base of the root zone. (RD req. 1, 2, 7, 8, 10, 11, 13, 16)	1.) Review and compare files test 0a.v22 and Test0a.v21. See Attachment A2-1, Item 6.. 2.) Review file Test0a.v22. Refer to file test0a.v26 to compare soilmm with scapmm See Attachment A2-1, Common parameters to calculate scapmm. 3.) Compare rocktype imbibe (ksat) (Test0a.v26) to net infil. (Test0a.v22).	✓ ✓ ✓	
Test 0B: Validation of 4JA.S01 Daily Climate Input Format				
0B.1	On successful execution of the program, the following output files have been created: Test0b.1, Test0b.2, Test0b.3, Test0b.4, Test0b.5, Test0b.6, Test0b.7, Test0b.8, Test0b.9, Test0b.10, Test0b.v21, Test0b.v22, Test0b.v23, Test0b.v24, Test0b.v25, and Test0b.v26. (RD requirements 1, 13, 14, 15, 16)	(1) Program output, the yearfile.txt file, verifies this activity; (2) Program output, the Test 0b.v23 verifies this and other output of all "v" files.	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
0B.2.	The output in the daily water balance output file Test0b.v21 indicates daily water balance results, with each line of output corresponding to the daily time sequence provided by the input file 4jas01. The total number of days indicated by the output in Test0a.v21 is 36524. (RD requirements 1, 7, 8, 13)	Review files Test0b.v21 and 4jas01. See Attachment A2-1, Item 7, for examples to verify daily time sequence function.	✓	
0B.3.	The output in the summary output file (Test0b.v23) provides a listing of the input and output file names specified in the model control file, along with a listing of annual results for the 100 years simulated and average annual rates for the full simulation period (RD requirement 9).	Review file Test0b.v23	✓	
0B.4.	The output in the average annual map file (Test0b.v24) corresponds to average annual rates for all water balance terms at all active model nodes defined in the geospatial parameter input file T1.w20. All Output terms in the average annual map file (Test0b.v24) are non-uniform (the values vary from node to node), with the exception of the snowfall, snowmelt, and sublimation terms (these are all 0). (RD requirements 1, 4, 15)	Review Test0b.v24 and T1.w20 files to compare. Note: The boundary nodes identified by -3 in the T1.w20 file are not active nodes and are not included in the 0a.v24 file.	✓	
0B.5.	The average annual run-on term shows a general increase in magnitude from higher elevation to lower elevation model nodes (RD req. 1, 11, 15)	Review/compare file Test0b.v24 and Test0b.v26. See Attachment A2-1, Item 8.	✓	
0B.6.	The absolute values of the program calculated volume balance terms in the daily output file (mass balance, mass balance 2) do not exceed 1E-8 for any day simulated (RD req. 7, 13)	Review file..	✓	
0B.7.	The absolute values of the program calculated volume balance terms in the average annual map file Test0b.v24 (mass-balance, max-balance, mass-balance #2) do not exceed 1E-8 for any model node. (RD req. 7, 15)	A hand-calculation check of the results in Test0b.v24 shows that the solution to equations 1 of the RD has an absolute value no greater than 1E-4 for any model node.	✓	
0B.8.	The absolute value of the program calculated volume balance term in the annual summary file Test0b.v23 (mass-balance) does not exceed 1E-5 for any year simulated (RD requirements 7, 14)	Review file.	✓	
Test 0C: Validation of Rosalia.inp Daily Climate Input Format				
0C.1.	On successful execution of the program, the following output files have been created: Test0c.1, Test0c.2, Test0c.3, Test0c.3, Test0c.4, Test0c.5, Test0c.6, Test0c.7, Test0c.8, Test0c.9, Test0c.v21, Test0c1.v22, Test0c2.v22, Test0c3.v22, Test0c4.v22, Test0c.v23, Test0c.v24, Test0c.v25, and Test0c.v26. (RD requirements 1, 13, 14, 15, 16)	(1) Program output, the yearfile.txt file, verifies this activity; (2) Program output, the Test 0c.v23 verifies this and other output of all "v" files.	✓ ✓	
0C.2.	The output in the daily water balance output file Test0c.v21 indicates daily water balance results, with each line of output corresponding to the daily time sequence provided by the input file Rosalia.inp. The total number of days indicated by the output in Test0a.v21 is 16070. (RD requirements 1, 7, 8, 13)	Review files Test0c.v21 and Rosalia.inp.	✓	
0C.3.	The output in the summary output file (Test0c.v23) provides a listing of the input and output file names specified in the model control file, along with a listing of annual results for the all years simulated and average annual rates for the full simulation period. Missing years are not included in the annual results. (RD requirement 9)	Review Test0c.v23 file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
0C.4.	The output in the average annual map file (Test0c.v24) corresponds to average annual rates for all water balance terms at all active model nodes defined in the geospatial parameter input file T1.w20. Output terms in the average annual map file are non-uniform (results indicate variability from node to node), including the snowfall, snow-melt, and sublimation terms. (RD requirements 1, 4, 5, 15). Note: The boundary nodes identified by -3 in the T1.w20 file are not active nodes and are not included in the 0c.v24 file.	Review test0c.v24 and T1.w20 files.	✓	
0C.5.	The average annual run-on term shows a general increase in magnitude from higher elevation to lower elevation model nodes (RD req. 1, 11, 15)	Review/compare file Test0c.v24 and Test0c.v26.	✓	
0C.6.	The absolute values of the program calculated volume balance terms in the daily output file (mass balance, mass balance 2) do not exceed 1E-8 for any day simulated	Review file.	✓	
0C.7.	The absolute values of the program calculated volume balance terms in the average annual map file Test0b.v24 (mass-balance, max-balance, mass-balance #2) do not exceed 1E-8 for any model node	Review file.	✓	
0C.8.	The absolute value of the program calculated volume balance term in the annual summary file Test0c.v23 (mass-balance) does not exceed 1E-5 for any year simulated (RD requirements 7, 14)	Review file.	✓	
0C.9.	For all days of the simulation where precipitation occurred and the average daily air temperature was < 0 degrees C, some percentage of the total precipitation occurred as snow (RD requirements 4, 5, 13)	Review file.test0c.v21.	✓	
0C.10.	(1) The output in the secondary output file Test0c.v26 indicates the thickness of the root zone layers for each node are defined as a function of soil depth and input parameters in the model control file, as documented in USGS (2001). (2) The soil and rock properties listed for the root zone layers for each node are consistent with the soil and rock parameters defined in the model control file. For example, layer 1 thickness (top layer of root zone) does not exceed RDEPTH1, and layer 4 thickness (bedrock layer of root zone) does not exceed RDEPTH4. (3) The root-zone effective water storage capacity (porosity – wilting point) for all layers at all nodes is dependent on the layer thickness and the soil properties at all nodes. (RD requirements 1, 2, 16)	1.) Review output file to verify. 2.) Verify by comparison of MCF, Test0c.v26, and T1w.20 file. See Attachment A2-1, Item 2. 3.) Review Infilv2.for file for calculation.	✓ ✓ ✓	
0C.11.	For day 406 of the simulation (day 41 of year 1952) the daily water balance map file Test0c1.v22 is consistent with the results in the daily output file Test0c.v21 in terms of precipitation, net infiltration, runoff, and run-on. For example, for day 406, precipitation is 0, but snow-melt is occurring. The root zone layers are close to full saturation at some nodes , and thus runoff is being generated at some nodes.	Review Test0c.v21 and Test0c.v22 files. See Attachment A2-1, Common parameters. Use spreadsheet functions to check for averages for test0c.v22 file parameters (example calculations included in Attachment A2-1, Item 9).	✓	
0C.12.	The average daily net infiltration, runoff, and run-on terms in the daily output file Test0c.v21 must agree (to within 0.0001 mm) with the results calculated using the output from the daily water balance map file for day 406 (Test0c1.v22). (Test0c1.v22 is brought into a spreadsheet, and the results for all nodes are averaged (the columns are averaged). These results must be in agreement with the results for day 406 in the output file test0c.v21.)	Review Test0c1.v21 and .v22 files. See Attachment A2-1, Conversions to convert from mm/day to cfs.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
0C.13.	(1) For the results included in the daily water balance map file, the water content of any layer cannot exceed the absolute water storage capacity of that layer (layer porosity times layer thickness, in mm, as evaluated by the output provided in test0c.v26). (2) The net infiltration rate at any node cannot exceed the bulk saturated hydraulic conductivity at the base of the root zone. (RD req. 1, 2, 7, 8, 10, 11, 13, 16)	1.) Review scapmm (1through4) from test0c.v26 file and soilmm (1 through 4) from test0c.v22 file. 2.) Compare imbibe (ksat) from .v26 with infilmm from file .v22.	✓ ✓	
Test 0D: Validation of the Average Annual Map Output File Format for Post-Processing Application using the Software Routine MAPADD20				
0D.1.	On successful execution of the program for all three test runs, the following output files have been created: Test0d1.1, Test0d1.2, Test0d1.3, Test0d1.3, Test0d1.4, Test0d1.5, Test0d1.6, Test0d1.v21, Test0d1.v22, Test0d1.v23, Test0d1.v24, Test0d1.v25, Test0d1.v26, Test0d2.1, Test0d2.2, Test0d2.3, Test0d2.3, Test0d2.4, Test0d2.5, Test0d2.6, Test0d2.v21, Test0d2.v22, Test0d2.v23, Test0d2.v24, Test0d2.v25, Test0d2.v26, Test0d3.1, Test0d3.2, Test0d3.3, Test0d3.3, Test0d3.4, Test0d3.5, Test0d3.6, Test0d3.v21, Test0d3.v22, Test0d3.v23, Test0d3.v24, Test0d3.v25, and Test0d3.v26. (RD requirement 1)	Review Test0d1, Test0d2, and Test0d3 folders to find program run output files "yearfile" and ".v23". Also can review folder contents to verify presence of all ".v" output files.	✓	
0D.2.	On execution of the post-processing routine MAPADD20 using the files Test0d1.v24, Test0d2.v24, and Test0d3.v24 as input, the output files Test0d.dat, Test0d.err, Test0d.out, and Test0d.sum are generated. (RD requirement 6)	Review the three Test0d ".v24" files and compare to the post-processing Test0d.dat file. Review other post processing output files.	✓	
0D.3.	The results in the summary output file Test0d.sum indicate an average precipitation rate of approximately 517.3 mm/year, an average net infiltration rate of approximately 20.2 mm/year, and an average runoff rate of approximately 32.5 mm/year.	Review file.	✓	
0D.4.	The main output file Test0d.dat lists results for a total of 1574 model nodes (each line of output corresponds to results for a single model node, with the exception of the first line of output which is the header line).	Review the three Test0d ".v24" files and compare to the post-processing Test0d.dat	✓	
0D.5.	The main output file Test0d.dat indicates results that are in agreement with the results in the summary file Test0d.sum. For example, the average precipitation rate across all 1574 model nodes is approximately 517.3 mm/year, the maximum precipitation rate across all model nodes is approximately 548.9 mm/year, and the minimum precipitation rate across all model nodes is 494.1 mm/year.	Review file.	✓	
0D.6.	The second line of output in the file Test0d.dat (first line below the header) corresponds to the second line of output in test0d1.v24. Line 805 in the file Test0d.dat corresponds to the second line of output in test0d2.v24. . Line 1227 in the file Test0d.dat corresponds to the second line of output in test0d3.v24.	Review files. See Attachment A2-1, Item 10 for comparison.	✓	
Test 1A: Basic Water Volume Balance Check				
1A.1.	The following output files have been generated by the code (1) test1a.1, teat1a.2, test1a.3, test1a.3, test1a.4, test1a.5, test1a.6, test1a.7, test1a.8, test1a.9, test1a.10, test1a.11, test1a.12, test1a.13, test1a.14, test1a.15, test1a.16, (2) test1a.v21, test1a.v22, test1a.v23, test1a.v24, test1a.v25, and test1a.v26. (RD requirements 13, 14, 15, 16)	(1) The yearfile.text program output file verifies this. (2) Test1a.v23 output file verifies output of all ".v" files.	✓ ✓	
1A.2.	The output in the daily output file test1a.v21 indicates daily results (each line of output in the file corresponds to the daily time sequence provided by the input file mod3-ppt.dat) and all results are 0. (RD requirements 7, 13)	Review files.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
1A.3.	The output in the summary output file test1a.v23 provides a listing of annual results and average annual rates, and all results are 0. (RD requirements 7, 14).	Review file	✓	
1A.4.	(1) The output in the average annual map file test1a.v24 corresponds to average annual rates for all water balance terms at all active model nodes defined in the geospatial parameter input file T1.w20. (2) The format for test1a.v24 is correct according to input format requirements for the post-processing routine MAPADD20.exe, as documented in USGS (2001). All results in test1a.v24 are 0. (RD requirements 7, 15) Note: The boundary nodes identified by -3 in the T1.w20 file are not active nodes and are not included in the 0a.v24 file.	1.) Review test1a.v24 and T1.w20 files. 2.) Compare test1a.v24 with test0d.v24 used as input to test with Mapadd20 to ensure comparable format. See Attachment A2-1, Item 4 to confirm successful MAPPADD20 output.	✓ ✓	
1A.5.	All output terms in the daily map file Test1a.v22 for day 5549 (day 70, year 1995) are 0 except for the node x-y coordinates and the simulation day number. (RD req. 7, 16)	Review file.	✓	
1A.6	The output in the secondary output file Test1a.v26 indicates that the thickness of the root zone layers for each node is 0. The soil and rock properties listed for the root zone layers for each node are consistent with the soil and rock parameters defined in the model control file. The root-zone effective water storage capacity (porosity – wilting point) for all layers at all nodes is 0 because all layers have a thickness of 0. (RD requirements 1, 7, 16)	Review files. See Attachment A2-1, Item 1, for example of model control file.	✓	
Test 1B: Basic Water Volume Balance Check with Saturated Initial Conditions				
1B.1.	The following output files have been generated by the code: test1b.1, test1b.2, test1b.3, test1b.3, test1b.4, test1b.5, test1b.6, test1b.v21, test1b.v22, test1b.v23, test1b.v24, test1b.v25, and test1b.v26. (RD requirements 1, 13, 14, 15, 16)	1.) The yearfile.text program output file verifies this. 2.) Test1b.v23 output file verifies output of all ".v" files.	✓ ✓	
1B.2.	The absolute value of the average annual rates for the change in root zone water content, runoff, and run-on, in the summary output file Test1b.v23, the average annual map file Test1b.v24, and the daily output file Test1b.v21, are equal (to within 1E-5 mm/year). All other components of the water balance are 0 in all three output files (RD requirements 7, 13, 14, 15)	Review files.	✓	
1B.3.	Except for the first day of the simulation, all terms of the water balance are 0 for all 2192 days simulated. On the first day simulated, the absolute value of the change in root zone water content is equal to both the runoff and run-on terms (to within 1E-9 mm). (RD requirement 6, 7, 8)	Review file test1b.v24	✓	
1B.4.	(1) The daily map file Test1b.v22 indicates that runoff occurred on the first day of the simulation and was routed to downstream nodes. (2) The average runoff generated across all nodes is equal to the average run-on depth calculated based on the outflow from the model domain (to within 1E-9 mm). (RD requirements 6, 7, 8, 13, 16)	1.) Review file. 2.) Review files test1b.v21 and test1b.v22. See Attachment A2-1, Conversions to derive outflow from Test1b.v22 parameters.	✓ ✓	
1B.5.	(1) For all nodes with runoff greater than 0 in the daily map file Test1b.v22, the water content of layer 3 is equal to the total storage capacity of layer 3 for each node. (2) Only the third root zone layer has a water content greater than 0. (3) For all nodes with no runoff, the water content of layer 3 is less than the total storage capacity of layer 3. (Rd requirements 1, 2, 6, 7, 8, 16)	1.) Review files test1b.v22 and test1b.v26 for layer parameters. 2.) Review file test1b.v22 3.) Review file test1b.v22 See Test1b.v26 for scapmm, or Attachment A2-1, Common Parameters, for scapmm calculation.	✓ ✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
1B.6.	The average runoff and run-on terms calculated from the daily map file Test1b.v22 are equal to the average daily runoff and run-on terms for day 1 in the daily output file Test1b.v21 (to within 1E-9 mm). (RD requirements 7, 8, 13, 16)	See files Test1b.v22 and Test1b.v21. Use spreadsheet functions to calculate averages. (ave. values calculated using spreadsheet function shown to right of data.)	✓	
Test 1C: Basic Water Volume Balance Check with Saturated Initial Conditions				
1C.1.	The following output files have been generated by the code: test1c.1, test1c.2, test1c.3, test1c.3, test1c.4, test1c.5, test1c.6, test1c.v21, test1c1.v22, test1c2.v22, test1c3.v22, test1c4.v22, test1c.v23, test1c.v24, test1c.v25, and test1c.v26. (RD requirements 1, 13, 14, 15, 16)	1.) The yearfile.text program output file verifies this. 2.) Test1c.v23 output file verifies output of all ".v" files.	✓ ✓	
1C.2.	After the first day of the simulation, the average daily change in the root zone water content is equal to the daily net infiltration rate in the daily output file Test1c.v21 (to within 1E-9). (RD requirements 2, 6, 7, 8, 13)	Review file test1c.v21.	✓	
1C.3.	The net infiltration rate decreases throughout the simulation period (the maximum net infiltration rate occurs on the first day, the minimum net infiltration rates occurs on the last day). (RD requirement 2, 6, 7, 8, 13)	Review file test1c.v21	✓	
1C.4.	Although coupled surface water routing is enabled, runoff equals run-on on the first day of the simulation (to within 1E-8 mm) because the root zone profile is fully saturated (RD requirements 2, 6, 7, 8, 13)	Review file Test1c.v21	✓	
1C.5.	1) The daily map file for the first day of the simulation, Test1c1.v22, indicates a fully saturated root zone and net infiltration rates equal to the bulk saturated hydraulic conductivity at the bottom of the root zone for all model nodes (2) The water content for all root zone layers except for layer 1 is 0.(3) Runoff is generated at all nodes, and (4) the run-on term increases as node elevation decreases. (5) The total runoff generated equals the outflow from the model domain. (RD requirements 2, 6, 7, 8, 10, 16)	1.) This is evaluated by a comparison with the output provided in the root-zone parameter file, Test1c.v26. 2.) Review file test1c.v22 3.) Same as (2). 4.) Review files test1c.v22 and test1c.v26 5.) Review output file test1c.v23	✓ ✓ ✓ ✓ ✓	
1C.6.	1) The daily map file for the second day of the simulation, Test1c2.v22, indicates that runoff and run-on are not occurring. (2) The net infiltration rate at each node still equals the bulk saturated hydraulic conductivity. (3) The decrease in the root zone water contents from the first day to the second day of the simulation is equal to the net infiltration rate at each node. (RD requirements 2, 6, 7, 8, 10, 16)	Review files test1c2.v and test1c2.v22	✓	
1C.7.	1) The daily map file Test1c3.v22 for simulation day number 22 indicates that net infiltration is no longer occurring at some model nodes. (2) For these nodes the root zone water content equals the soil field capacity. (3) For all nodes where the root zone water content is greater than the soil field capacity, net infiltration is occurring and is equal to or less than the bulk saturated hydraulic conductivity (imbibe) at the bottom of the root zone. (RD requirements 2, 6, 7, 8, 10, 16)	1.) See file. 2.) See Test1c3.c22 and test1c.v26 files. 3.) Review test1c3.v22 and test1c.v26. See Attachment A2-1, Common Parameters.	✓ ✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
1C.8.	The daily map file Test1c4.v22 for the last day of the simulation (day number 2192) indicates that net infiltration has stopped at all nodes except for the bottom node at the mouth of the watershed model domain (the lowest elevation node). For all other nodes, the water content of the root zone is equal to the soil field capacity. The water content for the bottom node still exceeds the soil field capacity because this node has thicker soil and thus holds a larger volume of water in the root zone. (RD requirements 2, 6, 7, 8, 10, 16)	1.) See file. 2.) See Test1c3.c22 and test1c.v26 files.	✓ ✓	
Test 1D: Basic Water Volume Balance Check with Layered Root Zone				
1D.1.	The output in the secondary output file Test1d.v26 indicates that the thickness of root zone layers 1 and 2 is 0.1 meters for all nodes. The thickness for root zone layers 3 and 4 is variable and is dependent on soil depth. The thickness of root zone layer 4 is zero when soil depth is 0.5 meters or greater. The total thickness of the root zone is less than or equal to 0.5 meters for all nodes, except for the bottom node at the mouth of the watershed, which has a root zone thickness of 2 meters (RD requirements 1, 2, 7, 16)	Review test1d.v26 file.	✓	
1D.2.	The water storage capacity for the bedrock layer (layer 4) is 0 because the effective root zone porosity term for the bedrock layer (RKPOR) is 0. (RD requirements 1, 2, 16)	Review test1d.v26 file..	✓	
1D.3	All results in the daily output file Test1d.v21 are identical (to within 0.00001 mm/year) to the results in the daily output file for test 1c (Test1c.v21). (RD requirements 2, 6, 7, 8, 10, 13)	Review files	✓	
1D.4.	All results in the average annual map file Test1d.v24 are identical to the results in the average annual map file for test 1c (Test1c.v24). (RD requirements 2, 6, 7, 8, 10, 15)	Review files.	✓	
1D.5.	The daily map file for the first day of the simulation (Test1d1.v22) indicates that the net infiltration rate for day 1 at each node is equal to the bulk saturated hydraulic conductivity at the bottom of the root zone (based on comparison with the results in test1d.v26). (RD requirements 2, 6, 7, 8, 10, 16)	Review files.	✓	
1D.6.	The daily map file for the first day of the simulation (Test1d1.v22) indicates that the water content of all root zone layers in the soil profile at each node is equal to the porosity times layer thickness (in mm) at each node (the soil profile is fully saturated). (RD requirements 2, 6, 7, 8, 10, 13)	Review files 1d1.v22 and 1d.v26	✓	
1D.7.	The daily map file for the 22nd day of the simulation (Test1d3.v22) indicates that the water content of all root zone layers in the soil profile at nodes where net infiltration is 0 is equal to the soil field capacity times layer thickness (in mm). For nodes where net infiltration is greater than 0, the water content for each layer is greater than the field capacity water content but less than or equal to the full saturation water content (porosity times layer thickness). For nodes where net infiltration is greater than 0, the relative saturation of layer 2 is greater than or equal to the relative saturation of layer 1, and the relative saturation of layer 3 is greater than or equal to the relative saturation of layer 2 (RD requirements 2, 6, 7, 8, 10, 13)	Review file test1d.v22 and test1d.v26. See Attachment A2-1, Common Parameters and Item 11 for examples from test. Note: rkpor is user specified input variable which defines effective bedrock storage capacity	✓	
Test 1E: Basic Water Volume Balance Check with Layered Root Zone				
1E.1.	The output in the secondary output file Test1e.v26 indicates that the storage capacity for root zone layer 4 is greater than 0 (RD requirements 1, 2, 7, 16)	Review file. Not true for ia numbers 18 and 123.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
1E.2.	The results in the daily output file Test1e.v21 indicate that the absolute value in the change in the root zone water content, runoff, and run-on, for the first day of the simulation are all less than for the first day of the simulation in test1d. The net infiltration rate on the first day of the simulation is identical for the two test cases. (RD requirements 2, 6, 7, 8, 10, 13)	Review files test1e.v21 and test1d.v21.	✓	
1E.3.	The net infiltration rates in both the daily output file Test1e.v21 and the average annual map file Test1e.v24 are identical to the net infiltration rates obtained for test 1d. (RD requirements 2, 6, 7, 8, 10, 15)	Review test1e.v21, test1e.v24, test1d.v21, and test1d.v24 files.	✓	
1E.4.	The daily map file for the first day of the simulation (Test1e1.v22) indicates that the net infiltration rate for day 1 at each node is equal to the bulk saturated hydraulic conductivity (imbibe) at the bottom of the root zone (as indicated by results in Test1e.v26), and that layer 4 is fully saturated. (RD requirements 2, 6, 7, 8, 10, 16)	Review files.	✓	
1E.5.	1) The daily map file for the 22nd day of the simulation (Test1e3.v22) indicates that the water content of all soil root zone layers at each node where net infiltration is 0 is equal to the soil field capacity times the layer thickness in mm. (2) The water content for layer 4 is equal to the bedrock effective storage capacity times the bedrock layer thickness, in mm. (3) For nodes where net infiltration is greater than 0 the water content for each soil layer is greater than the soil field capacity water content but less than or equal to porosity times layer thickness, in mm (the full saturation water content). For nodes where net infiltration is greater than 0, the average relative saturation of the root zone layers increases from top to bottom. (RD requirements 2, 6, 7, 8, 10, 13)	1.) Review file test1e3.v22 and test1e.v26. See Attachment A2-1, Common Parameters for calculation. 2.) Same as (1) 3.) Same as (1)	✓ ✓ ✓	
1E.6.	The daily map files for days 22 and 2192 indicate that the water content for layer 4 is equal to the effective root zone storage capacity for layer 4 (the relative saturation is 1 for both days). (RD requirements 2, 6, 7, 8, 10, 13)	Review files.	✓	
Test 1F: Basic Water Volume Balance Check with Layered Root Zone				
1F.1.	Comparison of the output files Test1f.v21 and Test1e.v21 indicates that the maximum daily net infiltration rate obtained for test case 1f is less than the maximum daily net infiltration rate obtained for test case 1e. (RD requirements 2, 6, 7, 8, 10, 13)	Review files.	✓	
1F.2.	Comparison of the output files Test1f.v21 and Test1e.v21 indicates that the runoff generated on the first day is greater for test case 1f. (RD requirements 2, 6, 7, 8, 10, 13)	Review files.	✓	
1F.3.	Comparison of the output files Test1f.v24 and Test1e.v24 indicates that the average annual net infiltration rate obtained for test case 1f is less than the average annual net infiltration rate obtained for test case 1e. (RD requirements 2, 6, 7, 8, 10, 15)	Review files. See Attachment A2-1, Item 12 for example of calculated averages.	✓	
1F.4.	1) Inspection of the daily output file Test1f.v21 indicates that the daily net infiltration rate increases from day 1 and reaches a maximum rate after approximately 1 year. (2) The maximum net infiltration rate is approximately equal (to within 2 significant figures) to the spatially average saturated hydraulic conductivity of the soil times 0.0001. (3) After approximately 2 years, the net infiltration rate begins to decrease. (RD requirements 1, 2, 6, 7, 8, 10, 13)	1.) See Attachment A2-1, Item 13. 2.) Review file test1f.v21 to determine max net infil and convert soilks to mm/day to compare. See Attachment A2-1 Item 13 for example. Refer to VTP, Table 1 test soil properties. 3.) Same as (1).	✓ ✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
1F.5.	1.) The daily map file for the first day of the simulation (Test1f1.v22) indicates that on day 1 net infiltration occurs only at nodes where layer 4 has a thickness of 0 (the root zone does not extend bedrock). (2) For these nodes, the net infiltration rate is equal to 0.0001 times the saturated hydraulic conductivity of the soil. (3) For all other nodes, the increase in the water content for layer 4 is equal to 0.0001 times the saturated hydraulic conductivity of the soil. (RD requirements 1, 2, 6, 7, 8, 10, 16)	1) Review test1f1.v22. 2) Same as Test 1F.4(2). 3) Review test1f1.v22 and VTP, Table 1 for test soil properties.	✓ ✓ ✓	
1F.6.	1.) The daily map file for the 22nd day of the simulation (Test1f2.v22) indicates that the water content for layer 4 has increased relative to the first day, but has not exceeded the effective storage capacity of layer 4 for locations where the thickness of layer 4 is greater than 0. (2) The average net infiltration rate for day 22 is equal to the average net infiltration rate for day 1. (RD requirements 2, 6, 7, 8, 10, 13)	1.) Review files test1f2.v22 and test1f.v26. 2.) Review files test1f1.v22 and test1f2.v22.	✓ ✓	
1F.7.	The daily map file for day 466 (Test1f3.v22) indicates that the water content for layer 4 has increased relative to the 22nd day, and has reached the effective bedrock storage capacity of all nodes in layer 4 except for the first node (the highest elevation node). For all nodes where layer 4 has reached the effective bedrock storage capacity, net infiltration is occurring and is equal to 0.0001 times the saturated hydraulic conductivity of the soil. (RD requirements 2, 6, 7, 8, 10, 13)	1.) Review test 1f3.v22 and test1f.v26 files. 2.) Review test1f.v26 file for rockmm and VTP, Table 1 for soilks.	✓ ✓	
1F.8.	1.) The daily map file for day 2192 (Test1f4.v22) indicates that the water content for layer 4 has increased relative to day 466, and is equivalent to the effective bedrock storage capacity times the layer thickness, in mm, of all nodes. (2) Net infiltration is occurring at only 2 nodes (node 1 and 75), and the water content of layer 3 is greater than field capacity water content for these 2 nodes. (3) The water content of all layers at all other 73 nodes is equal to the field capacity times the layer thickness, in mm times 1000, at each node. (RD requirements 2, 6, 7, 8, 10, 13)	1.) Review test1f4.v22 and test1f.v26 files for rockmm and cdepth4. 2.) Review files test1f4.v22 and test1f.v26. See Attachment A2-1, Common Parameters. 3.) Same as (2).	✓ ✓ ✓	
1F.9.	The results in the annual summary output file (Test1f.v23) are consistent with the results in the daily output file (Test1f.v21) and the average annual map file (Test1f.v24). The average annual rates for the water balance terms calculated using the results in the daily output file are equal (to within 1E-5) to the spatially averaged rates calculated using the results in the average annual map file. (RD requirements 7, 8, 13, 14, 15)	Review files. Use spreadsheet function to calculate averages and see Attachment A2-1, Item 5 as example of comparisons.	✓	
1F.10.	The water volume balance is satisfied using both equations 1 and 2 in the RD (to within 1E-8) for all days simulated based on the daily results in Test1f1.v21. (RD requirements 6, 7, 8, 13)	Review file. See Attachment A2-1, Item 14 for example calculation.	✓	
1F.11.	The water volume balance is satisfied using equation 1 (to within 1E-4 mm/year) for all model nodes based on the average annual results in Test1f.v24. (RD requirements 6, 7, 8, 15)	Review file. See Attachment A2-1, Item 14 for example calculation.	✓	
Test 2A: Potential Evapotranspiration Functions				
2A.1.	The results in the daily output file Test2a.v21 indicate that all components of the daily water balance are 0 throughout the simulation period, with the exception of potential evapotranspiration, which is greater than 0 throughout the simulation period. (RD requirements 1, 3, 13)	Review file.	✓	
2A.2.	The results in the daily output file Test2a.v21 indicate that potential evapotranspiration is correlated to the day of year (this is indicated by a plot of potential evapotranspiration versus day of year). A minimum potential evapotranspiration rate occurs on day 358 of each year, and a maximum potential evapotranspiration rate occurs on day 179 of each year. (RD requirements 1, 3, 13)	Review file. See Attachment A2-1, Item 15 for a plot.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
2A.3.	The results in the annual map file for the first year of the simulation (Test2a.1) indicate that total annual potential evapotranspiration for year 1980 is spatially variable across the model domain (variability is shown from node to node). (RD requirements 1, 4, 16)	Review file.	✓	
2A.4.	The total potential evapotranspiration rate for year 1980 (Test2a.1), averaged across all nodes, is equal to 1.26 times the total potential evapotranspiration term (PETRS) for 1980 in the annual summary file Test2a.v23. (RD requirements 14, 16)	Review files.	✓	
2A.5.	The average annual potential evapotranspiration rate indicated in Test2a.v23 is equal to 1.26 times the average annual potential evapotranspiration rate calculated using the results from the daily output file Test2a.v21. (RD requirements 3, 13, 14)	Review file Test2a.v23 (PET and PETRS)	✓	
Test 2B: Potential Evapotranspiration and Evapotranspiration Functions				
2B.1.	1). The results in the daily output file Test2b.v21 indicate a decrease in the seasonal variability of modeled potential evapotranspiration. (2) The maximum daily potential evapotranspiration rate is less than the maximum for test 2a, and the minimum is greater than the minimum for test 2a. (RD requirement 3)	1.) Review file. This may be verified by visual inspection of file or by a plot of potential evapotranspiration versus day of year. 2.) Compare files test2b.v21 and test2a.v21	✓ ✓	
2B.2.	The average annual potential evapotranspiration rate calculated using the daily output file for test 2b is less than the average annual rate calculated using test 2a. (RD requirement 3)	Compare test2b.v23 and test2a.v23 files.	✓	
2B.3.	The results in the daily output file Test2b.v21 indicate that coupled surface water flow routing and net infiltration have occurred in conjunction with evapotranspiration from the root zone. (Coupled surface water flow routing is indicated by an average infiltrated run-on term greater than 0 for the second day of the simulation, and an average runoff term greater than the average run-on term for the first day of the simulation). (RD requirements 6, 7, 8, 13)	Review file.	✓	
2B.4.	The results of the daily output file Test2b.v21 indicate that the maximum net infiltration rate occurs on the first day of the simulation, and continually decreases for all successive days. The daily net infiltration rate reaches 0 before the last day of the simulation. The maximum evapotranspiration rate does not occur on the first day of the simulation, but increases with an increase in the potential evapotranspiration rate until reaching a maximum rate between day 30 and day 60, and then continually decreases for the remainder of the simulation. (RD requirements 3, 6, 7, 8, 9, 10)	Review file.	✓	
2B.5.	The daily water balance calculated using the results in Test2b.v21 and equations 1 and 2 in the RD is satisfied for all days of the simulation (to within 1E-8 mm/day). (RD requirements 7, 8, 13)	Review file. See Attachment A2-1, Item 14 for example.	✓	
2B.6.	The results of the average annual map file Test2b.v24 indicate that the average annual evapotranspiration rate is variable across model nodes. A maximum evapotranspiration rate occurs for the model node 75 (at the base of the test watershed T1.w20) which has the greatest soil thickness (and thus the greatest root zone thickness). (RD requirements 4, 9, 15)	Review file.	✓	
2B.7.	The average annual water balance calculated using the average annual rates in Test2b.v24 indicate that equation 1 of the RD is satisfied (to within 1E-4 mm/year).	Review file. See Attachment A2-1, Item 14 for example	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
Test 2C: Potential Evapotranspiration and Evapotranspiration Functions				
2C.1.	1.) The results in daily output file Test2c.v21 indicate a constant daily air temperature of 0.7 degrees C, and (2) a decrease in both the average annual potential evapotranspiration rate and the average annual evapotranspiration rate relative to the results obtained for test 2b. (RD requirements 3, 7, 9, 13)	1.) Review file test1c.v21.	✓	
		2.) Review and compare files test2b.v23 and test1c.v23.	✓	
2C.2.	The average annual net infiltration rate is greater for test 2c relative to the rate obtained for test 2b. (RD requirements 7, 9, 10, 13)	Review files test1b.v23 and test1c.v23	✓	
2C.3.	The results of the average annual map file Test2c.v24 indicate that the actual average annual evapotranspiration rate is variable across model nodes. A maximum evapotranspiration rate occurs for the model node 75 (at the base of the test watershed T1.w20) which has the greatest soil thickness (and thus the greatest root zone thickness). (RD requirements 4, 9, 15)	Review file test2c.v24, and refer to test2c.v26 for soil cdepth4.	✓	
2C.4.	The results of the average annual map files for test cases 2b and 2c (Test2b.v24 and Test2c.v24) indicate that average annual evapotranspiration rate for test 2b is greater than the rate for test 2c at all nodes. (RD requirements 4, 9, 15)	Review file. See Attachment A2-1, Item 16 for averages.	✓	
2C.5.	The average annual water balance calculated using the average annual rates in Test2b.v24 indicates that equation 1 of the RD is satisfied at all model nodes (to within 1E-4 mm/year). (RD requirements 7, 8, 15)	Review file. See Attachment A2-1, Item 14 for example.	✓	
2C.6.	Comparison of the results in the annual summary files for test cases 2b and 2c (Test2b.v23 and Test2c.v23) indicate that evapotranspiration rates are higher for test case 2b during the first 2 years of the simulation, and higher for test case 2c during the last 2 years of the simulation.	Review files Test2b.v23 and Test2c.v23.	✓	
2C.7.	1.) The results in the annual map file for the first year of the simulation (Test2c.1) indicate that total annual potential evapotranspiration for year 1980 is spatially variable across the model domain (variability is shown from node to node). 2.) Overall variability in potential evapotranspiration for 1980 is decreased relative to the 1980 annual results for test 2a (the variance of potential evapotranspiration calculated using the results for all nodes is less for test 2c relative to the calculated variance for test 2a). results for. (RD requirements 1, 4, 16)	1.) Review file. 2.) Confirm statistical parameter values See Attachment A2-1, Item 18.	✓ ✓	
2C.8.	The total potential evapotranspiration rate for 1980, averaged across all nodes, is equal to 1.26 times the total potential evapotranspiration term (PETRS) for year 1980 in the annual summary file Test2a.v23. (RD requirements 14, 16)	Review file.	✓	
2C.9.	1.) The results in the daily output file Test2c.v21 indicate that potential evapotranspiration is correlated to the day of year. A minimum potential evapotranspiration rate occurs on day 358 of each year, and a maximum potential evapotranspiration rate occurs on day 167 of each year. (RD requirements 1, 3, 13)	Review file. This can be verified by a plot of potential evapotranspiration versus day of year using spreadsheet functions.. See Attachment A2-1, Item 13 for example of plot.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
Test 2D: Potential Evapotranspiration and Evapotranspiration Functions				
2D.1.	1) The results in daily output file Test2d.v21 indicate a constant day of year number equal to 355, and a constant positive daily air temperature close to 0 degrees C (within 1 degree). Daily potential evapotranspiration is a constant for each day of the simulation. (2) Based on calculations made using the first 2192 days simulated (1980-95), the average annual potential evapotranspiration rate calculated using the results from Test2d.v21 is less than the average annual rate calculated using Test2c.v21 (RD requirements 1, 3, 13)	1) Review file test2d.v21 2) Compare files test2d.v23 and test2c.v23	✓ ✓	
2D.2.	Based on calculations made using the first 2192 days simulated, the average annual net infiltration rate calculated using the results from Test2d.v21 is greater for test 2d relative to the rate obtained for test 2c. (RD requirements 7, 9, 10, 13)	Review files test2d.v21 and test2c.v21. Use spreadsheet functions to calculate averages. See Attachment A2-1, Item 17 for calculated averages.	✓	
2D.3.	The results in the daily output file Test2d.v21 indicate that the maximum daily evapotranspiration rate occurs on the first day of the simulation. (RD requirements 6, 7, 8, 9, 13)	Review file. Use spreadsheet function to sort in descending order.	✓	
2D.4.	The results of the annual map file for year 1980 (Test2d.1) indicate that the actual annual evapotranspiration and the annual potential evapotranspiration rates are variable across model nodes. The annual potential evapotranspiration rate shows higher spatial variability (the calculated coefficient of variation is higher) relative to the results obtained for both tests 2c (Test2c.1) and 2a (Test2a.1). (RD requirements 1, 3, 4, 9, 16)	1.) Review file. 2.) Review files. See Attachment A2-1, Item 18 for calculated coefficient of variation.	✓ ✓	
2D.5.	The daily water balance calculated using the results in Test2d.v21 indicate that equations 1 and 2 of the RD is satisfied for all days simulated (to within 1E-8 mm). (RD requirements 7, 13)	Review file Test2d.v23. See Attachment A2-1, Item 14 for example.	✓	
Test 2E: Potential Evapotranspiration and Evapotranspiration Functions				
2E.1.	1.) The results in daily output file Test2d.v21 indicate a constant day of year number equal to 171, and a constant positive daily air temperature close to 0 degrees C (within 1 degree C). Daily potential evapotranspiration is a constant for each day of the simulation. (2) Based on calculations made using the first 2192 days simulated (1980-95), the average annual potential evapotranspiration rate calculated using the results from Test2e.v21 is greater than the average annual rate calculated using Test2c.v21 (RD requirements 1, 3, 13)	1.) Review file. 2.) Review files. See Attachment A2-1, Item 19 for calculated averages.	✓ ✓	
2E.2.	Based on calculations made using the first 2192 days simulated, the average annual net infiltration rate calculated using the results from Test2e.v21 is less than the rate calculated using the results from Test2c.v21 (RD requirements 7, 9, 10, 13)	Review files. See Attachment A2-1, Item 14 for calculated averages.	✓	
2E.3.	The results in the daily output file Test2e.v21 indicate that the maximum daily evapotranspiration rate occurs on the first day of the simulation. (RD requirements 6, 7, 8, 9, 13)	Review file.	✓	
2E.4.	The results of the annual map file for year 1980 (Test2e.1) indicate that the actual annual evapotranspiration and the annual potential evapotranspiration rates are variable across model nodes. The annual potential evapotranspiration rate shows lower spatial variability (the calculated coefficient of variation is lower) relative to the results obtained for all previous tests (Test2a.1, Test2b.1, Test2c.1, and Test2d.1). (RD requirements 1, 3, 4, 9, 16).	Review file. See Attachment A2-1, Item 18 for comparison of variability.	✓	
2E.5.	The daily water balance calculated using the results in Test2e.v21 indicate that equations 1 and 2 of the RD are satisfied for all days simulated (to within 1E-8 mm). (RD requirements 7, 13)	Review file. See Attachment A2-1, Item 14 for example of calculation.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
Test 2F: Potential Evapotranspiration and Evapotranspiration Functions				
2F.1.	The results in daily output file Test2f.v21 indicate a constant potential evapotranspiration rate of 5 mm/day for all days of the simulation. The maximum evapotranspiration rate is less than the potential evapotranspiration rate, and occurs on the first day of the simulation. (RD requirements 1, 3, 6, 7, 9, 13)	Review file.	✓	
2F.2.	The results in daily output file Test2f.v21 indicate that the maximum net infiltration rate is less than the bedrock saturated hydraulic conductivity, and occurs on the first day of the simulation. (Note: The maximum net infiltration rate occurs on the first day of the simulation because evapotranspiration is maximized for the top layer of the root zone. Infiltration into the rock layer from overlying soil layers is replacing water.)	Review file Test2f.v21 and see Attachment A2-1, Item 20.	✓	
2F.3.	1.) The results in daily output file Test2f.v21 indicate that runoff and run-on are generated on the first day of the simulation. (Note: The runoff depth is less than 70 mm because evapotranspiration and net infiltration are calculated first. The run-on depth is less than the runoff depth because coupled surface water routing is enabled and run-on is allowed to infiltrate into the soil profile as downstream routing occurs.) (2) A small amount of storage capacity is available during routing because evapotranspiration has decreased the water content of the top root zone layer (RD requirements 2, 6, 7, 8, 9, 10, 11, 13, 16)	1.) Review file Test2f.v21. 2.) . This is validated by inspection of the daily map file Test2f1.v22 for day 1 of the simulation.	✓ ✓	
2F.4.	The results in daily output file Test2f.v21 indicate that the net infiltration rate reaches 0 within the first year of the simulation (1980), while the evapotranspiration rate continues through approximately 1984 before reaching 0. (RD requirements 6, 7, 9, 10, 13)	Review file.	✓	
2F.5.	The daily water balance calculated using the results in Test2f.v21 indicate that equations 1 and 2 of the RD are satisfied for all days simulated (to within 1E-8 mm/day). (RD requirements 7, 13)	Review file. See Attachment A2-1, Item 14.	✓	
2F.6.	The total change in the zone water content, calculated using the results from the daily output file Test2f.v21, is exactly –300 mm. This is the total amount of water available to evapotranspiration, runoff, and net infiltration, based on the initial root zone water content of 400 mm. (RD requirements 7, 8, 13, 14, 15)	Review file to confirm sum of del-soil is 300mm.	✓	
2F.7.	(1) The daily map file for the first day of the simulation (Test2f1.v22) indicates that the first (top) layer of the root zone has a water content at or very close to the total storage capacity (total storage capacity (saturation) for layer 1 = 0.3 x 0.3 m = 90 mm). (2) The second root zone layer is fully saturated and has a water content of 210 mm at all nodes (the storage capacity for layer 2 = 0.3 x (1.0 - .3 m) = 210 mm). The water content of layer 3 is 0.0 mm at all nodes because the thickness of layer 3 is 0 meters. (3) Layer 4 (the rock layer) has a water content of 30 mm at all nodes, which is equal to the effective root zone storage capacity of the rock layer (0.03 x 1 meter = 30 mm). This indicates that the effective storage capacity of the rock layer has been filled by water infiltrating from the overlying soil, and causes runoff to be approximately 70 mm, not 100 mm. (RD requirements 2, 16)	Review files Test 2f1.v22 and Test 2f.v26 for layer variables.. See Attachment A2-1, Common Parameters.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
2F.8.	The daily map file for the first day of the simulation (Test2f1.v22) indicates all nodes with 0 mm run-on (totout) show a slight decrease in water content for the top layer (this is due to evapotranspiration). All nodes with a run-on term greater than 0 show the water contents for layers 1 and 2 at full saturation (the total soil water content is 300 mm). The runoff depth at all nodes is uniform and slightly less than 70 mm. (RD requirements 2, 3, 4, 7, 8, 9, 16)	Review file.	✓	
2F.9.	The daily map file for the first day of the simulation (Test2f1.v22) indicates that the net infiltration rate at all nodes is uniform and is slightly less than the bulk saturated hydraulic conductivity of the underlying bedrock (1 mm).	Review file and refer to test2f.v26 file or model control file for ksat.	✓	
2F.10.	1.) The daily map file for the second day of the simulation (Test2f2.v22) indicates that the first and second layers of the root zone have water contents slightly less than full saturation (soilporo is 0.3m3/m3), with the relative saturation of layer 2 higher than layer 1. (2) The water contents for layers 1 and 2 are not uniform and reflect higher water contents for nodes having infiltrated run-on from the first day. (3) The water content of the rock layer is still equal to the effective root zone storage capacity of 30 mm. (RD requirements 2, 4, 7, 8, 9, 11, 16)	1. and 3) Review file. 2.) Review file Test2f1.v22 and compare nodes showing runoff (totout) with Test2f2.v22 node layer(s) water content.	✓ ✓	
2F.11.	The daily map file for the second day of the simulation (Test2f2.v22) indicates that the net infiltration rate at all nodes is slightly less than the net infiltration rate for the first day (this is because as the top layer dries the transpiration rate at the bottom of the root zone increases). The net infiltration rates are non-uniform and are higher for nodes where run-on infiltrated from the first day. (RD requirements 2, 4, 7, 8, 9, 10, 11, 16)	Review file.	✓	
2F.12.	1.) The daily map file for the 10th day of the simulation (Test2f3.v22) indicates that the saturation of the top layer is much less (about 50%) than the saturation of layer 2, which is still close to full saturation (about 100%). The net infiltration rate at all nodes has decreased relative to day 2. (2) The water contents of the 2 soil layers are not uniform, with slightly higher water contents occurring at nodes where run-on infiltrated. The water content of the bottom rock layer is still at the effective storage capacity of 30 mm for all nodes, thus net infiltration is still occurring, but has been reduced relative to rates for day 2 (this is because transpiration from the rock layer has increased). (RD requirements 2, 4, 7, 8, 9, 10, 11, 16)	1.) Review files Test2f2.v22 and Test2f3.v22. 2.) Review Test2f3.v22 and compare Test2f3.v22 soilmm(1) and soilmm(2) with totout inTest 2f1.v22.	✓ ✓	
2F.13.	1.) The daily map file for the 57th day of the simulation (Test2f4.v22) indicates that the water content of the top layer has reached the wilting point (and thus the field capacity) of 30 mm water depth (relative saturation of 33.3%) for all nodes (both evapotranspiration and infiltration from the top layer has stopped at all nodes). The water content of layer 2 is still slightly greater than field capacity (70 mm) at all nodes (thus both transpiration and infiltration from layer 2 are still occurring). The water content of the bottom rock layer is still at the effective storage capacity of 30 mm for all nodes. (Thus net infiltration is still occurring, but has been reduced relative to rates for day 10. The reduction is caused by an increase in the transpiration rate from the rock layer as the soil layers have dried up). The net infiltration rate is uniform across all nodes. (RD requirements 2, 4, 7, 8, 9, 10, 16)	1.) Review file Test2f4.v22. See Attachment A2-1, Common Parameters. 2.) Review file.	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
2F.14.	The daily map file for the 58th day of the simulation (Test2f5.v22) indicates that the water content of the second layer has reached the wilting point (and thus the fully saturated water content) of 70 mm water depth (relative saturation of 33.3%) for all nodes. Both evapotranspiration and infiltration from the soil profile has stopped at all nodes. The water content of the bottom rock layer is still at the effective storage capacity of 30 mm for all nodes, thus net infiltration is still occurring, but has been reduced relative to rates for day 57. The net infiltration rates are not uniform; nodes where run-on occurred have higher net infiltration rates. (This is the last day that net infiltration can occur). (RD requirements 2, 4, 7, 8, 9, 10, 16)	Review file.	✓	
2F.15.	The daily map file for the 59th day of the simulation (Test2f6.v22) indicates that the water content of the rock layer is uniform and slightly less than the storage capacity of 30 mm at all nodes. The net infiltration is 0, but transpiration is still occurring from the bottom rock layer (this is indicated by the daily output file, Test2f.v21). (RD requirements 2, 4, 7, 8, 9, 10, 16)	Review tiles Test2f6.v22 and Test2f.v21.	✓	
2F.16.	The daily map file for the 2192nd day of the simulation (Test2f7.v22) indicates that the water content of the rock layer is 0. Net infiltration and transpiration have stopped (refer to results in Test2f.v21). There is exactly 100 mm of water in the soil profile at all nodes. (RD requirements 2, 4, 7, 8, 9, 10, 16)	Review tiles Test2f7.v22 and Test2f.v21.	✓	
Test 2G: Potential Evapotranspiration and Evapotranspiration				
2G.1.	The results in daily output file Test2g.v21 indicate that the daily net infiltration rate is 0 for all days of the simulation. The daily evapotranspiration rate is less than the daily potential evapotranspiration rate of 5 mm/day, and the maximum evapotranspiration rate occurs on the first day of the simulation. (RD requirements 6, 7, 8, 9, 10, 13)	Review file.	✓	
2G.2.	The results in the daily output file Test2g.v21 indicate that the runoff depth generated on day 1 is greater than the results for day 1 of test 2f (slightly less than 100 mm), and the total evapotranspiration depth for the simulation period is greater than results for test2f. (RD requirements 6, 7, 8, 9, 10, 11, 13)	Review files test2f.v21 and test2g.v21. See Attachment A2-1, Item 21 for sum of et's.	✓	
2G.3.	The daily map file for the first day of the simulation (Test2g1.v22) indicates that the water content of the soil profile is very close to full saturation (> 99%). The water content of the rock layer is slightly greater than 0 and is equal to the maximum daily infiltration rate from the soil. The water content of the second soil layer and the rock layer are uniform for all nodes, and the runoff depth is uniform across all nodes. (RD requirements 2, 6, 7, 8, 9, 10, 13, 16)	Review file. See Attachment A2-1, Common Parameters.	✓	
2G.4.	1.) The daily map file for day 10 of the simulation (Test2g3.v22) indicates that the saturation of the top layer has been considerably reduced (to about 70% of that for day 1) while the saturation of the second layer is still relatively high (> 90%). 2.) The saturation of the top layer is higher compared to results for day 10 of test 2f, while the saturation of the second layer is lower compared to results for day 10 of test 2f. (RD requirements 2, 6, 7, 8, 9, 10, 13, 16)	1.) Review files Test2g1.v22 and Test2g3.v22. 2.) Review files Test2g3.v22 and Test2f3.v22.	✓ ✓	
2G.5.	The daily map file for day 10 of the simulation (Test2g3.v22) indicates that the water content of the rock layer has increased and is uniform for all nodes, but is much less than 30 mm. (RD requirements 2, 4, 6, 7, 8, 9, 10, 16)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
2G.6.	1.) The daily map file for day 57 of the simulation (Test2g4.v22) indicates that the water content of the rock layer has increased relative to results for day 10, but is still much less than 30 mm. (2) The water content of the top layer has reached field capacity, and relative saturation of the second layer is greater than the results for day 57 of test 2f. (RD requirements 2, 6, 7, 8, 9, 10, 13, 16)	1.) Review file. 2.) Review files Test2g4.v22 and Test2f4.v22.	✓ ✓	
2G.7.	The daily map file for day 2192 of the simulation (Test2g7.v22) indicates that the water content of the rock layer is 0, and the soil profile water content is exactly 100 mm, with 30 mm in layer 1 and 70 mm in layer 2. (RD requirements 2, 6, 7, 8, 9, 10, 13, 16)	Review file.	✓	
Test 2H: Potential Evapotranspiration and Evapotranspiration Functions				
2H.1.	The results in daily output file Test2h.v21 indicate that the daily net infiltration rate is 0 for the first 2 to 7 weeks of the simulation. The daily evapotranspiration rate is less than the daily potential evapotranspiration rate of 5 mm/day, and the maximum evapotranspiration rate occurs on the first day of the simulation. (RD requirements 3, 6, 7, 8, 9, 10)	Review file.	✓	
2H.2.	1.) The results in the daily output file Test2h.v21 indicate that the runoff depth generated on day 1 is less than the result for test 2g. (2)The total evapotranspiration depth for the simulation period is greater than result for test 2f, but less than the result for test 2g. The total net infiltration depth is less than the result for test 2f, but greater than the result for 2g. (RD requirements 3, 6, 7, 8, 9, 10)	1.) Review files Test2h.v21 and Test2g.v21. (2) Review files Test2f.v21., Test2g.v21, and Test2h.v21. See Attachment A2-1, Item 21.	✓ ✓	
2H.3.	1.) The daily map file for the first day of the simulation (Test2h1.v22) indicates that the water content of the soil profile is very close to full saturation (> 99%). (2) The water content of the rock layer is 10 times the rock layer water content for test 2g on the first day of the simulation. (RD requirements 2, 3, 6, 7, 8, 9, 16)	1.) Review file Test2h1.v22. 2.) Review file Test2h1.v22 and Test2g1.v22	✓ ✓	
2H.4.	The daily map file for day 10 of the simulation (Test2h3.v22) indicates that the water content of the soil profile is slightly less then results for day 10 of test 2g. The water content of the rock layer is approximately 10 times the rock layer water content for test 2g on the day 10 of the simulation. (RD requirements 2, 3, 6, 7, 8, 9, 16)	Review files Test2h3.v22 and Test2g3.v22.	✓	
2H.5.	1.) The daily map file for day 57 of the simulation (Test2h4.v22) indicates that the water content of the rock layer has reached the effective storage capacity of 30 mm, and net infiltration is occurring. (2) The net infiltration rate is uniform across all model nodes, but is less than the net infiltration rate obtained for day 57 of test 2f because the soil saturated hydraulic conductivity (1E-01) is less than the bedrock bulk saturated hydraulic conductivity (1E00). (RD requirements 3, 6, 7, 8, 9, 10, 16)	1.) Review day 57 for Test2h4.v22 file. 2.) Review day 57 for Test2h.v21 and Test2f.v21 files. Refer to VTP, Table 1 or model control file for soil and rock properties.	✓ ✓	
2H.6.	The daily map file for day 2192 (Test2h7.v22) indicates that the water content of the rock layer has reached 0, and net infiltration is not occurring. The total water content of the soil profile is 100 mm. (RD requirements 2, 3, 6, 7, 8, 9, 10, 11, 16)	Review file.	✓	
Test 2I: Potential Evapotranspiration and Evapotranspiration Functions				
2I.1.	The results in daily output file Test2i.v21 indicate that the daily net infiltration rate is 0 for the first 2 to 7 weeks of the simulation. The daily evapotranspiration rate is less than the daily potential evapotranspiration rate of 2 mm/day, and the maximum evapotranspiration rate occurs on the first day of the simulation. (RD requirements 2, 3, 6, 7, 8, 9, 10, 13)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
2I.2.	The daily output file Test2i.v21 indicates that evapotranspiration is still occurring on the last day of the simulation. The minimum evapotranspiration rate occurs on the last day. (RD requirements 3, 6, 7, 8, 9, 13)	Review file.	✓	
2I.3.	The results in the daily output file Test2i.v21 indicate that the total change in root zone water content for the simulation period is slightly less than 300 mm. (RD requirements 2, 3, 6, 7, 8, 9, 10, 13)	Review file.	✓	
2I.4.	The results in the daily output file Test2i.v21 indicate that total net infiltration for the simulation period is greater than results obtained for test 2h. Total evapotranspiration for the simulation period is less than the results obtained for test 2h. (RD requirements 2, 3, 6, 7, 8, 9, 10, 13)	Review file. See Attachment A2-1, Item 21.	✓	
2I.5.	The daily map file for day 57 of the simulation (Test2i4.v22) indicates that the water content of layer 1 has reached field capacity of 30 mm, while the water content of layer 2 is higher than field capacity. The water content of the rock layer is 30 mm (at storage capacity). Net infiltration is occurring and is less than 1 mm/day. (RD requirements 2, 3, 6, 7, 8, 9, 10, 11, 16)	Review file.	✓	
2I.6.	The daily map file for day 2192 (Test2i7.v22) indicates that the water content of the rock layer has decreased to 0.0027 mm, and net infiltration is not occurring. The total water content of the soil profile is 100 mm. (RD requirements 2, 3, 6, 7, 8, 9, 10, 11, 16)	Review file.	✓	
Test2J: Potential Evapotranspiration and Evapotranspiration Functions				
2J.1.	The results in the root zone layer parameter file (Test2j.v26) indicate that the thickness of layer 1 is 0.3 meters, the thickness of layer 2 is 0.7 meters, the thickness of layer 3 is 1.0 meters, and the thickness of layer 4 (the rock layer) is 2.0 meters. (RD requirements 2, 16)	Review file.	✓	
2J.2.	The results in daily output file Test2j.v21 indicate that the daily net infiltration rate is exactly 1 mm/day on the first day of the simulation, and remains at 1 mm/day until the last day that net infiltration occurs in the simulation. (RD requirements 6, 7, 8, 9, 10, 13)	Review file.	✓	
2J.3.	The results in daily output file Test2j.v21 indicate that the daily evapotranspiration rate reaches 0 (ET stops) several weeks prior to the net infiltration rate reaching 0 mm/day (net infiltration stops). The maximum evapotranspiration rate occurs on the first day and is close to the potential evapotranspiration rate of 2 mm/day. (RD requirements 3, 6, 7, 8, 9, 10, 13)	Review file.	✓	
2J.4.	The results in daily output file Test2j.v21 indicate that the total change in the root zone water content for the period of the simulation is –390 mm. (RD requirements 3, 6, 7, 8, 9, 10, 13)	Review file.	✓	
2J.5.	The daily map file for day 1 of the simulation (Test2j1.v22) indicates that the water content of all 4 root zone layers is at the storage capacity of each layer (the root zone, including the bedrock layer, is fully saturated). (Note: Transpiration has not occurred from any layer underlying the top layer, and thus all water contents are uniform for all layers at all nodes). (RD requirements 2, 3, 6, 7, 8, 9, 10, 16)	Review files test2j2.v22 and test2j.v26 (for storage capacity variables). See Attachment A2-1, Item 3 for sample calculation.	✓	
2J.6.	1.) The daily map file for day 2 of the simulation (Test2j2.v22) indicates a decrease in water content for the top layer, but all three of the underlying layers remain at full saturation. (2)The net infiltration rate is exactly 1 mm/day at all nodes, because transpiration is not occurring from the rock layer. (RD requirements 2, 3, 6, 7, 8, 9, 10, 16)	1.) Review file. Compare to day 1 file, test2j1.v22. 2.) Review file.	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
2J.7.	1.) The daily map file for day 2192 of the simulation (Test2j7.v22) indicates that the water content of the top layer (layer 1) has reached the wilting point (30 mm). The water content for the 2 underlying soil layers is at field capacity (140 and 200 mm). The water content of the rock layer is equal to the effective storage capacity (40 mm). (2)These results are consistent with the results provided in the root zone layer parameter file (Test2j.v26). (RD requirements 2, 3, 6, 7, 8, 9, 10, 16)	`1.) Review file. 2.) Review files test2j7.v22 and test2j.v26.	✓ ✓	
Test2K: Potential Evapotranspiration and Evapotranspiration Functions				
2K.1.	The results in daily output file Test2k.v21 indicate that the maximum daily net infiltration rate is less than 1 mm/day, and occurs on the first day of the simulation. (RD requirements 6, 7, 8, 10, 13)	Review file.	✓	
2K.2.	The results in daily output file Test2k.v21 indicate that the daily net infiltration rate reaches 0 (net infiltration stops) before the evapotranspiration rate reaches 0 (ET stops). (RD requirements 6, 7, 8, 9, 10, 13)	Review file.	✓	
2K.3.	1.) The results in daily output file Test2k.v21 indicate that the total change in the root zone water content for the period of the simulation is –470 mm. (2) The total net infiltration amount (water depth) is less than the total net infiltration amount for test 2j. The total evapotranspiration amount is greater than the total evapotranspiration amount obtained for test 2j. (RD requirements 6, 7, 8, 9, 10, 13)	1.) Review file. 2.) Review file. See Attachment A2-1, Item 21.	✓ ✓	
2K.4	The daily map file for day 1 of the simulation (Test2k1.v22) indicates a uniform net infiltration rate of approximately 0.2 mm/day for all model nodes. (RD requirements 2, 6, 7, 8, 10, 16)	Review file.	✓	
2K.5.	The daily map file for day 1 of the simulation (Test2k1.v22) indicates the water content of all soil layers is at or slightly less than the total storage capacity (porosity x layer thickness, in mm). The water content of the rock layer (layer 4) is equal to the effective storage capacity of the rock layer (40 mm) at all nodes. (RD requirements 2, 6, 7, 8, 9, 10, 16)	Review file test 2k1.v22 and test2k.v26. See Attachment A2-1, Item 3 for sample calculation of storage capacity.	✓	
2K.6.	The daily map file for day 57 of the simulation (Test2k4.v22) indicates that the water content of the rock layer is less then the effective storage capacity of the rock layer (40 mm), and thus the net infiltration rate is 0 for all nodes. (RD requirements 2, 6, 7, 8, 9, 10, 16)	Review file. Refer to test2k.v26 file for determining effective storage capacity of rock layer (rkmm). See Attachment A2-1, Common Parameters, for calculation.	✓	
2K.7.	The daily map file for day 2192 of the simulation (Test2k7.v22) indicates that the water content of the top layer (layer 1) and the bottom soil layer (layer 3) is equal to the field capacity water content (0.2 times layer thickness of 0.3 m equals 60 mm). The water content of the second soil layer (layer 2) is equal to the field capacity water content (70 mm), and the water content of the rock layer is equal to 0. Water contents are uniform for all nodes. (RD requirements 2, 6, 7, 8, 9, 10, 16)	Review files 2k7.v22 and test2k.v26. See Attachment A2-1, Common Parameters, for example soil water content calculation.	✓	
Test 3A: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3A.1.	The results in the daily output file Test3a.v21 indicate that the daily net infiltration rate is equal to the bedrock bulk saturated hydraulic conductivity of 1 mm/day for all days where net infiltration is occurring. (RD requirements 7, 8, 10, 13)	Review file.	✓	
3A.2.	The results in the daily output file Test3a.v21 indicate that net infiltration is 0 mm/day during the first 24 days of the simulation. (RD requirements 7, 8, 10, 13)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3A.3.	The results in the daily output file Test3a.v21 indicate that the root zone has an increase in water content of 240 mm during the first 24 days of the simulation. (RD requirements 3, 7, 8, 10, 13)	Review file.	✓	
3A.4.	The total change in the root zone water content, based on the results in the daily output file Test3a.v21, is 440 mm. (RD requirements 3, 7, 8, 9, 10, 13)	Review file.	✓	
3A.5.	The results in the daily output file Test3a.v21 indicate that after 47 days the root zone is fully saturated and runoff is generated at a constant rate of exactly 9 mm/day. On the 47th day of the simulation, runoff occurs but is less than 9 mm (because the root zone profile is not fully saturated on day 46.) (RD requirements 2, 3, 7, 8, 10, 11, 16)	Review file.	✓	
3A.6.	The results in the daily output file Test3a.v21 indicate that outflow equals runoff for all days having runoff, because the root zone profile is fully saturated and evapotranspiration is disabled. (RD requirements 2, 3, 7, 8, 10, 11, 12, 16)	Review file test3a.v21 and refer to Test3a.v23 for summary run-off and outflow values.	✓	
Test 3B: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3B.1.	The results in the daily output file Test3b.v21 indicate that the daily net infiltration rate is 0 for all days in the simulation. (RD requirements 7, 8, 9, 10, 13)	Review file.	✓	
3B.2.	The results in the daily output file Test3b.v21 indicate that the change in the root zone water content is 10 mm/day and runoff is 0 mm/day for the first 6 days of the simulation. (RD requirements 7, 8, 9, 10, 13)	Review file.	✓	
3B.3.	The total change in the root zone water content, based on the results in the daily output file Test3b.v21, is less than 440 mm. (RD requirements 7, 8, 9, 10, 13)	Review file.	✓	
3B.4.	The results in the daily output file Test3b.v21 indicate that after the first 7 days of the simulation, the change in root zone water content is equal to 0.008467 mm/day for all days between (and including) day 275 and day 183 of the following year simulated (winter storms). (RD requirements 7, 8, 9, 10, 13)	Review file.	✓	
3B.5.	The results in the daily output file Test3b.v21 indicate that after the first 7 days of the simulation, the change in root zone water content is equal to 0.001411 mm/day for all days between (and including) day 185 and day 273 of each year simulated (summer storms). (RD requirements 7, 8, 9, 10, 13)	Review file.	✓	
3B.6.	The results in the daily output file Test3b.v21 indicate that outflow is slightly less than runoff for all days having runoff, because infiltration of routed surface water is allowed (the root zone profile is not fully saturated). (RD requirements 7, 8, 9, 10, 11, 12, 13)	Review file. Note: outflow is named run-on in the DAYALL files	✓	
3B.7.	Comparison of results between the daily map files for days 1 and 2 of the simulation (test3b1.v22 and test3b2.v22) indicates a uniform increase of 10 mm in the water content of the top root zone layer. The water content for the remaining layers is unchanged. The net infiltration rate is 0 at all nodes. (RD requirements 2, 8, 9, 10, 13)	Review files test3b1.v22 and test3b2.v22.	✓	
3B.8.	1.) The results of the daily map file for day 48 of the simulation (test3b6.v22) indicates that the top root zone layer is close to full saturation. (2) Runoff is being generated at all nodes and the water content of the second root zone layer has increased slightly (by less than 1 mm relative to day 2 of the simulation). The net infiltration rate is 0 at all nodes.	1.) Review file. 2.) Review file test3b6.v22 and test3b2.v22.	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3B.9.	1.) The results of the daily map file for day 2192 of the simulation (test3b7.v22) indicates that the top root zone layer is at full saturation. (2) Runoff is being generated at all nodes and the water content of the second root zone layer has increased but is still well below the field capacity of 140 mm. The water content of the third root zone layer is equal to the wilting point water content (100 mm), and the water content of the forth root zone layer (the rock layer) is 0. The net infiltration rate is 0 at all nodes.	1.) Review file test 3b.v26 and see Attachment A2-1, Common Parameters for calculation of full saturation. Compare to test3b7.v22. 2.) Review file test3b7.v22	✓ ✓	
Test 3C: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3C.1.	The results in the daily output file Test3c.v21 indicate that starting on day 3, runoff is generated for all remaining days of the simulation, and is slightly less than 10 mm on all days. With the exception of the last day of the simulation, runoff is equal to run-on for all days simulated. (RD requirements 7, 8, 11, 12, 13)	Review file.	✓	
3C.2.	The results in the daily output file Test3c.v21 indicate that net infiltration is 0 mm/day during the first 847 days of the simulation. (RD requirements 7, 8, 10, 13)	Review file.	✓	
3C.3.	The results in the daily output file Test3c.v21 indicate that starting on day 4 of the simulation, the change in root zone water content is equal to the maximum infiltration rate, while the net infiltration rate is 0. The maximum infiltration rate is defined by storm duration and the soil saturated hydraulic conductivity (0.004234 mm/day for winter storms, 0.000706 mm/day for summer storms). (RD requirements 2, 6, 7, 8, 11, 12, 13)	Review file. Note explanation of calculation for soil ksat, Attachment A2-1, Item 22.	✓	
3C.4.	1.) The results in the daily output file Test3c.v21 indicate that starting on day 848, net infiltration occurs for the remainder of the simulation, at a rate much less than the bedrock bulk saturated hydraulic conductivity of 1 mm/day. (2) From day 849 on, the net infiltration rate is equal to the maximum soil infiltration rate (0.004234 mm/day for winter storms, and 0.000706 mm/day for summer storms). From day 849 on, the change in the root zone water content is 0 mm/day. (RD requirements 7, 8, 11, 12, 13)	1.) Review files test3c.v21 and test3c.v26 (for ksat (imbibe)). 2.) Review file test3c.v21.	✓ ✓	
3C.5.	The total change in the root zone water content, based on the results in the daily output file Test3c.v21, is 22.95 mm. (RD requirements 6, 7, 8, 10, 13)	Review file.	✓	
3C.6.	Comparison of the daily map files for days 1 and 2 of the simulation (test3c1.v22 and test3c2.v22) indicates a uniform increase of 10 mm in the water content of the root zone (9.9958 mm for layer 1 and 0.0042 mm for layer 4) for day 2 relative to day 1. The water content for all remaining layers is 0. The net infiltration rate is 0 at all nodes. (RD requirements 2, 6, 7, 8, 10, 16)	Review files.	✓	
3C.7.	Comparison of the daily map files for days 2 and 3 of the simulation (test3c2.v22 and test3c3.v22) indicates a uniform increase of approximately 0.004234 mm for the bottom root zone layer. The water content for layer 1 is exactly 30 mm, and a uniform runoff depth of 9.9915 mm is being generated at all model nodes. The water content for all remaining layers is 0. The net infiltration rate is 0 at all nodes. (RD requirements 2, 6, 7, 8, 10, 11, 13)	Review files.	✓	
3C.8.	Comparison of the daily map files for days 847 and 848 of the simulation (test3c4.v22 and test3c5.v22) indicates that the top soil layer has reached full saturation of 30 mm. A uniform net infiltration rate of 0.0008 mm/day is initiated on day 848 for all nodes as the water content of the bottom rock layer reaches the effective water storage capacity of 2.95 mm. The water content for all remaining layers is 0 mm at all nodes. A uniform runoff depth of 9.9958 mm is being generated at all model nodes. (RD requirements 2, 6, 7, 8, 10, 11, 16)	Review files.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3C.9.	Comparison of the daily map files for days 849 and 2192 of the simulation (test3c6.v22 and test3c7.v22) indicates that the water contents, net infiltration rates, and runoff rates are equivalent at all nodes for both days. The root zone water content is at full capacity (2.95 mm) and the net infiltration rate is ½ the saturated hydraulic conductivity of the soil (0.0042 mm/day). (RD requirements 2, 6, 7, 8, 10, 11, 16)	Review files.	✓	
Test 3D: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3D.1.	The results in the daily output file Test3d.v21 indicate that net infiltration is 0 for all days simulated. (RD requirements 6, 10, 13)	Review file.	✓	
3D.2.	The results in the daily output file Test3d.v21 indicate that, with the exception of the last day, runoff equals run-on for all days simulated, and the total runoff for the simulation period equals the total runoff generated for test 3c. (for tests 3c and 3d, runoff generation is controlled by the soil hydraulic conductivity, not by net infiltration or evapotranspiration). (RD requirements 6, 10, 11, 13)	Review files.	✓	
3D.3.	The results in the daily output file Test3d.v21 indicate that the evapotranspiration rate increases during the first several days (day 2 to day 11) of the simulation before reaching a steady rate of 0.004234 mm/day. This rate is maintained until day 184, at which time the rate diminishes over 5 to 10 days to a lower rate of 0.000706 mm/day. The new lower rate is maintained until day 274, at which time the rate gradually increase over the next 5 to 10 days until the higher rate of 0.004234 mm/day is attained. (RD requirements 3, 6, 7, 8, 9, 10, 13)	Review file.	✓	
3D.4.	Comparison of results between the daily map files for days 1 and 2 of the simulation (test3d1.v22 and test3d2.v22) indicates a smaller increase in the water content of layer 4 relative to results obtained for test 3c. The water content for the top soil layer increases from 20 mm on day 1 to 29.9958 mm on day 2 for all nodes. The water content for the bottom rock layer increases from 0 mm on day 1 to 0.0014 mm on day 2. The net infiltration rate is 0 at all nodes. (RD requirements 2, 6, 7, 8, 9, 10, 16)	Review files.	✓	
3D.5.	Comparison of results between the daily map files for days 25 and 46 of the simulation (test3d3.v22 and test3d4.v22) indicates that the water content of the top soil layer is at full saturation (30 mm), while the water content of the rock layer is being maintained at 0.0021 mm. A uniform runoff rate of 9.9958 mm/day is being generated at all nodes for both days. The net infiltration rate is 0 at all nodes for both days. (RD requirements 2, 6, 7, 8, 9, 10, 11, 16)	Review files.	✓	
3D.6.	The results of the daily map file for day 2192 of the simulation (test3d7.v22) indicate that water contents, net infiltration rates, and runoff rates are identical to the results obtained for day 46. (RD requirements 2, 6, 7, 8, 9, 10, 11, 16)	Review file.	✓	
Test 3E: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3E.1.	The results in the daily output file Test3e.v21 indicate that net infiltration is 0 for the first 13 days of the simulation. On the 14th day, net infiltration is approximately 1.116 mm/day and remains constant for the remainder of the simulation. (RD requirements 6, 7, 8, 9, 10, 13)	Review file.	✓	
3E.2.	The results in the daily output file Test3e.v21 indicate that, with the exception of the last day, runoff equals run-on for all days simulated. Runoff is 0 mm/day for the first 33 days of the simulation, and is 5 mm/day starting on day 35. The total runoff generated is less than the total runoff generated for test 3d. (RD requirements 6, 7, 8, 9, 10, 11, 12, 13)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3E.3.	The results in the daily output file Test3e.v21 indicate that the evapotranspiration rate is 0 mm/day for the first 10 days of the simulation. From day 11 to 13, the evapotranspiration rate increases to approximately 3.884 mm/day and remains at this rate for the remainder of the simulation. Starting on day 14, the sum of the daily evapotranspiration and net infiltration rate equals 5 mm/day. (RD requirements 3,,6, 7, 8, 9, 10, 13)	Review file.	✓	
3E.4.	The results in the daily output file Test3e.v21 indicate that the change in the root zone water content is 10 mm/day for the first 10 days of the simulation. All other terms of the daily water balance are 0 for the first 10 days, except for precipitation (10 mm/day), rain (10 mm/day), and potential evapotranspiration (5 mm/day). From day 11 to day 15, the change in the root zone water content decreases to 5 mm/day, corresponding to the initiation of evapotranspiration and net infiltration. From day 33 to 35, the change in root zone water content decreases from 5 to 0 mm/day, corresponding to the initiation of runoff. (RD requirements 6, 7, 8, 9, 10, 11, 13)	Review file.	✓	
3E.5.	Comparison of results between the daily map files for days 11 and 13 of the simulation (test3e2.v22 and test3e3.v22) indicates that the water content of layer 4 (the rock layer) is greater than 0. The water content increases from day 11 to day 12 but is less than the effective storage capacity of the rock layer (25 mm). The water content for soil layers 1 and 2 are at the field capacity water content (60 mm and 140 mm). Net infiltration and runoff are 0 at all nodes. (RD requirements 2, 3, 6, 7, 8, 9, 10, 11, 16)	Review files test3e2.v22 and test3e3.v22. See test3e.v26 for effective storage capacity (rkmm) and soil layer field capacities.	✓	
3E.6.	The results of the daily map file for day 14 of the simulation (test3e4.v22) indicates that a uniform net infiltration rate of approximately 1.1 mm/day is occurring at all nodes. The water content of the top soil layer is at the field capacity water content (60 mm) while the water content of the second soil layer has exceeded the field capacity water content (140 mm). The water content of the rock layer is at the effective water storage capacity of the rock layer (25 mm). Runoff and run-on (totout) are 0 at all nodes. (RD requirements 2, 6, 7, 8, 9, 10, 11, 12, 16)	Review file.	✓	
3E.7.	1.) The results of the daily map file for day 34 of the simulation (test3e5.v22) indicate that the water content of the root zone has reached the fully saturated water content of all layers (90 mm for layer 1, 210 mm for layer 2, and 25 mm for layer 4). (2) Runoff is being generated at all model nodes. The net infiltration rate is the same as for day 14. (RD requirements 2, 6, 7, 8, 9, 10, 11, 16)	1.) Review file. 2.) Review file test3e5.v22 and test 3e4.v22.	✓ ✓	
Test 3F: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3F.1.	The results in the daily output file Test3f.v21 indicate that evapotranspiration occurs on all days simulated, and the daily evapotranspiration rate is greater than for test case 3e. Starting on day 116 of the simulation, a constant evapotranspiration rate of approximately 4.65 mm/day is maintained for the remainder of the simulation. (RD requirements 3, 6, 7, 8, 9, 10, 13)	Review files.	✓	
3F.2.	1.) The results in the daily output file Test3f.v21 indicate that when runoff is greater than 0 mm/day, runoff is greater than run-on for all days simulated. Runoff and run-on are initiated (values are greater than 0 mm/day) on day 119. After day 121, the runoff and run-on terms are constant for the remainder of the simulation (with the exception of the last day, when run-on equals 0). (2) The maximum runoff rate and the total runoff generated for the simulation is less than results obtained for test case 3e. (RD requirements 6, 7, 8, 9, 10, 11, 12, 13)	1.) Review file test3f.v21 2.) Review files test3f.v21 and test3e.v21	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3F.3.	The results in the daily output file Test3f.v21 indicate that infiltrated run-on (run-infil) occurs starting on day 120. From day 122 on, the infiltrated run-on term remains constant at approximately 1.07 mm/day. (RD requirements 6, 7, 8, 9, 10, 13)	Review file.	✓	
3F.4.	The results in the daily output file Test3f.v21 indicate that net infiltration is initiated on day 22. Starting on day 23, net infiltration remains constant at approximately 4.61 mm/day for the remainder of the simulation. The maximum daily net infiltration rate and the total net infiltration amount for the simulation are greater than results obtained for test case 3e. (RD requirements 6, 7, 8, 9, 10, 13)	Review file.	✓	
3F.5.	The results of the daily map file for day 22 of the simulation (test3f2.v22) indicates that a uniform net infiltration rate of approximately 4.5 mm/day is occurring at all nodes. The water content of the rock layer is at the effective storage capacity of the rock layer (25 mm). The water content of the soil layers is slightly below the field capacity water content of the 2 soil layers (60 mm for layer 1, 140 mm for layer 2). Runoff and run-on are 0 at all nodes. (RD requirements 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 16)	Review file test3f2.v22 and see test3f-v26 for effective storage capacity of rock layer (rkmm) and field capacity water content (fc x cdepth x 1000).	✓	
3F.6.	1.) The results of the daily map file for day 119 of the simulation (test3f4.v22) indicates that a uniform net infiltration rate of approximately 4.6 mm/day is occurring at all nodes.(2) The water content of the bottom soil layer has reached the fully saturated water content of that layer (210 mm). (3) The water content of the top soil layer is slightly less than the fully saturated water content of 90 mm, and is variable across model nodes (this is in response to variable amounts of infiltrated run-on combined with evapotranspiration). (4) A uniform runoff amount of approximately 0.58 mm is being generated at all nodes, but the run-on amount is approximately 0 at all nodes. (RD requirements 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 16)	1.) Review file. 2.) Review file. See Attachment A2-1, Common Parameters for sample calculation of variable. 3.) Same as (2). 4.) Review file.	✓ ✓ ✓ ✓	
3F.7.	1.) The results of the daily map file for day 120 of the simulation (test3f5.v22) indicates that the water content of the top soil layer has reached the fully saturated water content (90 mm) for some, but not all, model nodes. (2) For those nodes with the top soil layer at the saturated water content, the surface water run-on term is greater than 0. (RD requirements 2, 4, 6, 7, 8, 11, 12, 16)	Review file.	✓	
Test 3G: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3G.1.	The results in the daily output file Test3g.v21 indicate that evapotranspiration occurs on all days simulated, and the daily evapotranspiration rate is on average greater than for test case 3f. Starting on day 479 of the simulation, a constant evapotranspiration rate of approximately 4.82 mm/day is maintained for the remainder of the simulation. (RD requirements 3, 6, 7, 8, 9, 10, 13)	Review file test3g.v21. See Attachment A2-1, Item 23 for comparison with 3f.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3G.2.	1.) The results in the daily output file Test3g.v21 indicate that runoff and run-on are initiated on day 493. From day 493 on, runoff and run-on are generated, and runoff is greater than run-on for all days. From day 499 on, runoff and run-on are constant, with runoff approximately 0.68 mm/day and run-on approximately 0.21 mm/day. (2) For all days simulated having runoff and run-on greater than 0, the runoff and run-on rates are less than the runoff and run-on rates generated for test case 3f. (RD requirements 3, 6, 7, 8, 9, 10, 11, 12, 13)	1.) Review file test3g.v21 2.) Review files test3g.v21 and test3f.g21	✓ ✓	
3G.3.	The results in the daily output file Test3g.v21 indicate that net infiltration is initiated on day 43. Starting on day 44, net infiltration remains constant at approximately 4.96 mm/day for the remainder of the simulation, which is greater than the net infiltration rate obtained for test case 3f. (RD requirements 6, 7, 8, 9, 10, 13)	Review files test3g.v21 and test3f.g21.	✓	
3G.4.	1.) The results of the daily map file for day 1 of the simulation (test3g1.v22) indicates water contents greater than 0 for 3 soil layers at all model nodes. The water content for each of the 3 soil layers is uniform across all nodes. (2) The water content of soil layer 1 (the top layer) is approximately 35.9 mm, which shows an increase in water content of less then 10 mm relative to the wilting point water content of 30 mm. The water content of the 2 lower soil layers is at the wilting point water content (70 mm for layer 2, 100 mm for layer 3). (3) The water content of the rock layer is 0 mm. (RD requirements 2, 3, 4, 6, 7, 8, 16)	1.) Review file. 2.) Review file. 3.) Review file.	✓ ✓ ✓	
3G.5.	The results of the daily map file for day 43 of the simulation (test3g2.v22) indicates water contents slightly below the field capacity water content for the top 3 soil layers (60 mm for layer 1, 140 mm for layer 2, and 200 mm for layer 3). The water content of the rock layer is equal to the rock layer storage capacity of 40 mm. A uniform net infiltration rate of approximately 1.55 mm/day is occurring at all model nodes. Runoff and Run-on are 0 at all nodes. (RD requirements 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 16)	Review files test3g2.v22 and test3g.v26.	✓	
3G.6.	The results of the daily map file for day 44 of the simulation (test3g3.v22) indicates water contents slightly below the field capacity water content for the top 2 soil layers (60 mm for layer 1, 140 mm for layer 2). The water content of the 3rd soil layer is slightly greater than the field capacity water content of 200 mm. The water content of the rock layer is equal to the rock layer storage capacity of 40 mm. A uniform net infiltration rate of approximately 4.96 mm/day is occurring at all model nodes. Runoff and Run-on are 0 at all nodes. (RD requirements 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 16)	Review file.	✓	
3G.7.	1.) The results of the daily map file for day 493 of the simulation (test3g5.v22) indicates water contents slightly below the saturated water content of 90 mm for the top soil layer. (2) The water content of the three lower root zone layers is at full saturation for all three layers (210 mm for layer 2, 300 mm for layer 3, 40 mm for layer 4). A uniform net infiltration rate of approximately 4.96 mm/day is occurring at all model nodes. (3) A uniform runoff rate of approximately 0.08 mm/day is occurring at all nodes, while run-on is 0 at all nodes. (RD requirements 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 16)	1.) Review files 3g5.v22 and 3g.v26. 2.) Review file 3g5.v22. 3.) Review file 3g5.v22.	✓ ✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3G.8.	The results of the daily map file for day 499 of the simulation (test3g7.v22) indicates water contents slightly below the saturated water content of 90 mm for most nodes in the top soil layer. For those nodes having water contents of 90 mm for the top soil layer, the run-on term is greater than 0 mm. The water content of the three lower root zone layers is at the storage capacity of all three layers (210 mm for layer 2, 300 mm for layer 3, 40 mm for layer 4). A uniform net infiltration rate of approximately 4.96 mm/day is occurring at all model nodes. Runoff is being generated at all model nodes, but is not uniform across all model nodes. (RD requirements 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 16)	Review file.	✓	
Test 4A: Infiltration and Coupled Surface Water Flow Routing				
4A.1.	The results in the daily output file Test4a.v21 indicate that runoff is initiated on day 46. (From day 46 through day 58, outflow (run-on) is less than runoff because surface water flow is allowed to infiltrate into the deeper soils of the channel nodes.) From day 59 on, runoff and run-on equal 10 mm/day and all other terms of the daily water balance (except precipitation and rain) are 0. (Starting on day 59, the root zone profile is fully saturated at all nodes, and run-on equals runoff because net infiltration and evapotranspiration cannot occur.) (RD requirements 4, 6, 7, 8, 11, 12, 13)	Review file.	✓	
4A.2.	The results in the daily output file Test4a.v21 indicate that the infiltrated run-on (run-infil) term is greater than 0 only for days 47 through 59 (this is the period during which routed surface water infiltrates into the deeper soils of the channel nodes). The infiltrated run-on term is 0 for all other days of the simulation. (RD requirements 4, 6, 7, 8, 11, 12, 13)	Review file.	✓	
4A.3.	The results in the average annual map file Test4a.v24 indicate that the average annual infiltrated run-on rate is greater than 0 only for channel nodes (channel nodes are identified as the nodes with 6 meters of soil). The run-on rates are variable across model nodes, and the highest run-on rate of approximately 260,000 mm/year occurs for the node at the mouth of the watershed (the last node listed in the output file), which is a channel node. (RD requirements 4, 6, 7, 8, 11, 12, 15)	Review files Test4a.v24 for run-infil and Test4a.v26 for soil thickness. Note: The channel nodes are identified in lines 25, 34, 43, 45, 53, 62, 68, 71, 73, 74, and 75 of the files.	✓	
4A.4.	The results of the daily map file for day 1 of the simulation (test4a1.v22) indicates water contents greater than 0 for 3 soil layers at all channel nodes. The water content of the top soil layer at all nodes equals the wilting point water content (30 mm) plus 10 mm. The water content for the second soil layer is at the wilting point water content (70 mm) for all nodes, and the water content of the third soil layer for channel nodes is also at the wilting point water content (500 mm). The water content for the bedrock layer is 0 at all model nodes. (RD requirements 2, 4, 6, 7, 8, 9, 16)	Review file. See Test 4A.3, Note, for channel node identification.	✓	
4A.5.	1.) The results of the daily map file for day 45 of the simulation (test4a2.v22) indicates that all upland nodes (nodes with 1 meter soil thickness) are fully saturated. The water content of the two soil layers is at the fully saturated water content (90 mm for layer 1, 210 mm for layer 2). The water content of the rock layer is at the effective storage capacity water content for the rock layer (250 mm). (2) For channel nodes, the water content of the top two soil layers is at the field capacity water content (60 mm for layer 1, 140 mm for layer 2) and the bottom soil layer water content is less than the field capacity water content (1000 mm). Net infiltration and runoff are 0 at all nodes. (RD requirements 2, 4, 6, 7, 8, 9, 10, 11, 12, 16)	1.) Review files test4a2.v22 and test4a.v26. See Test 4A.3, Note, for channel node identification. 2.) See Attachment A2-1, Edit	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4A.6.	1.) The results of the daily map file for day 46 of the simulation (test4a3.v22) indicates a runoff amount of 10 mm at upland nodes, while runoff is 0 at all channel nodes. The run-on terms for all upland nodes are variable in increments of 10 mm, while the run-on terms for channel nodes are in variable increments of less than 10 mm. (2) The layer 3 water content for channel nodes indicates an increase in water content greater than 10 mm relative to day 45 for all channel nodes. (3) The water content of the top soil layer is greater than the field capacity water content of 60 mm for all channel nodes. The run-on term for the node at the mouth of the watershed (the last node listed in the output file) is less than the run-on for the upstream channel node (the second to last node listed in the output file). (RD requirements 2, 4, 6, 7, 8, 9, 10, 11, 12, 16)	1.) Review files test4a3.v22 and test4a.v26. 2.) Review files test4a2.v22 and test4a3.v22. 3.) Review file test4a3.v22. See Test 4A.3, Note, for channel node identification.	✓ ✓ ✓	
4A.7.	The results of the daily map file for day 58 of the simulation (test4a5.v22) indicates that layers 1 and 2 are fully saturated. For channel nodes, layer 3 is fully saturated at a water content of 1,500 mm. For upland nodes, the water content of the rock layer is at the effective storage capacity water content of the rock layer (250 mm). Runoff is not yet occurring at the channel nodes. (RD requirements 2, 4, 6, 7, 8, 9, 11, 12, 16)	Review file. Refer to file test4a.v26 and Attachment A2-1, Common Parameters	✓	
4A.8.	The results of the daily map file for day 59 of the simulation (test4a6.v22) indicates a uniform runoff amount of 10 mm at all model nodes. The root zone is fully saturated, with a water content of 1500 mm for the third soil layer at all channel nodes. The run-on terms are variable in increments of exactly 10 mm for all model nodes, and the highest run-on amount of 740 mm occurs for the node at the mouth of the watershed. (This run-on amount is consistent with 10 mm of runoff being generated at 74 upstream nodes, and an infiltrated run-on rate of 0 mm at all nodes because there is no available storage capacity in the root zone.) (RD requirements 2, 4, 6, 7, 8, 9, 11, 12, 16)	Review file. See Test 4A.3, Note, for channel node identification.	✓	
4A.9.	The results of the daily map file for day 60 of the simulation (test4a7.v22) indicates that all results are equivalent to results obtained for day 59, thus showing that steady-state conditions have been achieved. (RD requirements 2, 4, 6, 7, 8, 9, 10, 11, 12, 16)	Review file.	✓	
Test 4B: Infiltration, Net Infiltration, and Coupled Surface Water Flow Routing				
4B.1.	The results in the daily output file Test4b.v21 indicate that runoff is initiated on day 46, but outflow (run-on) from the watershed does not occur until day 57. Outflow from the watershed increases from day 57 through day 60, and remains constant at approximately 9.3 mm/day for the remainder of the simulation. From day 60 on, outflow (run-on) is equal to runoff. (RD requirements 6, 7, 8, 11, 12, 13)	Review file.	✓	
4B.2.	The results in the daily output file Test4b.v21 indicate that the infiltrated run-on (run-infil) term is greater than 0 only for days 47 through 60 (this is the period during which routed surface water infiltrates into the deeper soils of the channel nodes). The infiltrated run-on term is 0 for all other days of the simulation. (RD requirements 6, 7, 8, 11, 12, 13)	Review file.	✓	
4B.3.	The results in the daily output file Test4b.v21 indicate that from day 46 through day 56, run-on is 0 and runoff is equal to the following day's infiltrated run-on (run-infil). (RD requirements 6, 7, 8, 11, 12, 13)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4B.4.	The results in the daily output file Test4b.v21 indicate that net infiltration is initiated on day 48, 2 days after the initiation of runoff. The net infiltration rate increases from day 48 through day 51. From day 51 on, the net infiltration rate remains constant at approximately 0.73 mm/day. (RD requirements 6, 7, 8, 10, 11, 12, 13)	Review file.	✓	
4B.5.	The results in the average annual map file Test4b.v24 indicate that the average annual infiltrated run-on (run-infil) and net infiltration rates are greater than 0 only for channel nodes (nodes with 6 meters of soil). The net infiltration rates for channel nodes are not uniform. The runoff rate is higher for upland nodes relative to channel nodes. The run-on rates are variable across all model nodes, and the highest run-on rate of approximately 245,000 mm/year occurs for the node at the mouth of the watershed (the last node listed in the output file). (RD requirements 6, 7, 8, 10, 11, 12, 15)	Review file. See Test 4A.3, Note, for channel node identification.	✓	
4B.6.	The results of the daily map file for day 46 of the simulation (test4b2.v22) indicates water contents greater than 0 for the 2 soil layers and the rock layer at all upland nodes, and for 3 soil layers at all channel nodes. For the upland nodes, the root zone profile is fully saturated with a uniform water content of 90 mm for layer 1, 210 mm for layer 2, and 250 mm for layer 4. Runoff is 10 mm at all upland nodes, and 0 mm at all channel nodes. For the channel nodes, the water content of the top 2 soil layers is at the field capacity water content (60 mm for layer 1, 140 mm for layer 2). The water content of the third soil layer is variable across channel nodes, in increments of 10 mm, from a minimum of 880 mm to a maximum of 940 mm. Runoff and run-on are 0 at all channel nodes, while run-on is variable (in increments of 10 mm) for upland nodes. (RD requirements 2, 6, 7, 8, 11, 12, 16)	Review file. See Test 4A.3, Note, for channel node identification.	✓	
4B.7.	1.) The results of the daily map file for day 48 of the simulation (test4b4.v22) indicates net infiltration of 5 mm has occurred at some (but not all) channel nodes. (2.) At all channel nodes where net infiltration is occurring, the water content of the third soil layer is greater than the fully saturated water content of 1000 mm. (3.)Runoff is 10 mm at all upland nodes. Runoff and run-on are 0 at all channel nodes. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1.) Review file 2.) Review file. 3.) Review file. See Test 4A.3, Note, for channel node identification	✓ ✓ ✓	
4B.8.	The results of the daily map file for day 56 of the simulation (test4b5.v22) indicates a net infiltration rate of 5 mm/day for all channel nodes. Some (but not all) of the channel nodes have become fully saturated, with water contents of 90 mm for layer 1, 210 mm for layer 2, and 1500 mm for layer 3. The channel nodes have runoff rates of 5 mm/day, and have variable run-on rates in increments of 5 mm/day. Outflow from the watershed is not occurring because the node at the mouth of the watershed (the last node listed in the output file) has a runoff and run-on rate of 0 mm/day. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file. See Test 4A.3, Note, for channel node identification	✓	
4B.9.	The results of the daily map file for day 60 of the simulation (test4b9.v22) indicates that root zone is fully saturated at all model nodes. The water contents are 90 mm for layer 1, 210 mm for layer 2, 1500 mm for layer 3 (channel nodes only), and 250 mm for layer 4 (upland nodes only). All channel nodes have a net infiltration and runoff rate of 5 mm/day. The run-on rates are variable across all model nodes, with increments of 10 mm for upland nodes and 5 mm for channel nodes. The maximum run-on rate of 690 mm/day occurs for the node at the mouth of the watershed (the last node listed in the output file). (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file. See Test 4A.3, Note, for channel node identification	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
Test 4C: Infiltration, Net Infiltration, and Coupled Surface Water Flow Routing				
4C.1.	The results in the daily output file Test4c.v21 indicate that both runoff and runon are initiated on day 46. From day 46 through day 66, run-on is less than runoff. From day 67 on, run-on equals runoff. (RD requirements 6, 7, 8, 11, 12, 13)	Review file.	✓	
4C.2.	1) The results in the daily output file Test4c.v21 indicate that the infiltrated run-on (run-infil) term is greater than 0 for days 47 through 67 (this is the period during which routed surface water infiltrates into the deeper soils of the channel nodes). The infiltrated run-on term is 0 for all other days of the simulation. (2) The period for which infiltrated run-on occurs is longer compared to results obtained for test 4b. (RD requirements 6, 7, 8, 11, 12, 13)	1.) Review file. 2.) Review files Test4c.v21 and Test4b.v21. See Test 4A.3, Note, for channel node identification	✓ ✓	
4C.3.	The results in the daily output file Test4c.v21 indicate that net infiltration is initiated on day 50, 4 days after the initiation of runoff and run-on. From day 50 on, the net infiltration rate is constant at approximately 0.73 mm/day. (In contrast to results for test 4b, there is no period of increasing net infiltration because channel nodes are uniformly saturated from run-on) (RD requirements 6, 7, 8, 10, 11, 12, 13)	Review file.	✓	
4C.4.	The results in the average annual map file Test4c.v24 indicate that the average annual infiltrated run-on (run-infil) and net infiltration rates are greater than 0 only for channel nodes (nodes with 6 meters of soil). Unlike results obtained for test 4b, the net infiltration rates for channel nodes are uniform. (RD requirements 6, 7, 8, 10, 11, 12, 15)	Review file. See Test 4A.3, Note, for channel node identification	✓	
4C.5.	(1) Comparison of results between the daily map file for day 46 (Test4c2.v22) and 47 (Test4c3.v22) indicates a uniform increase in water content of approximately 40 mm for all channel nodes. All upland nodes are fully saturated and have a uniform runoff rate of 10 mm/day for both days. The run-on rates at all nodes are equivalent for both days. Net infiltration and runoff are 0 at all channel nodes for both days. (2) The water content of the bottom soil layer is uniform (982.1168 mm) across all channel nodes for both days, and is slightly less than fully saturated water content (1000 mm). (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1.) Review files Test4c.v22 and Tet4c3.v22. 2.) Review file. See Test 4A.3, Note, for channel node identification	✓ ✓	
4C.6.	1.) The results of the daily map file for day 50 of the simulation (test4c6.v22) indicates a uniform net infiltration rate of 5 mm/day at all channel nodes. (2) Runoff at all channel nodes is 0, and the water content of the third soil layer is uniform (1017.54 mm) and is slightly greater than the fully saturated water content of 1000 mm. (3) The run-on rates for all model nodes are equivalent to the run-on rates obtained for days 46 and 47. The highest run-on rate (305.434 mm) occurs for the node at the mouth of the watershed (the last node listed in the output file). (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1.) Review file. 2.) Review file. 3.) Review files Test4c2.v22, Test4c3.v22, and Test4c6.v22 See Test 4A.3, Note, for channel node identification	✓ ✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4C.7.	1.) The results of the daily map file for day 65 of the simulation (test4c7.v22) indicates a uniform net infiltration rate of 5 mm/day at all channel nodes. (2) Runoff at all channel nodes is 0, and the water content of the third soil layer is uniform and is equal to the full saturation water content of 1500 mm. (3) The run-on rates for all model nodes are equivalent to the run-on rates obtained for days 46, 47, and 50. (4) Relative to day 47, the water content of the second soil layer has increased uniformly for all channel nodes, but is less than the saturated water content of 210 mm. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1. Review file. 2.) Review files test4c7.v22 , and refer to test4c.v26 for saturated water content calculation variables 3.) Compare files test4c2.v22, test4c3.v22, test4c6,v22 and test4c7.v22. 4.) Review files test4c3.v22 and test4c7.v22. See Test 4A.3, Note, for channel node identification	✓ ✓ ✓ ✓	
4C.8.	The results of the daily map file for day 66 of the simulation (test4c8.v22) indicates that the root zone profile is fully saturated for all model nodes. For upland nodes, the water contents are 90 mm for layer 1, 210 mm for layer 2, and 250 mm for layer 4. For channel nodes, the water contents are 90 mm for layer 1, 210 mm for layer 2, and 1500 mm for layer 3. A uniform net infiltration rate of 5 mm/day is occurring at all channel nodes, but the runoff rate is 0 at all channel nodes. The run-on rates have increased for all channel nodes relative to day 65. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file.	✓	
4C.9.	The results of the daily map file for day 67 of the simulation (test4c9.v22) indicates that a uniform net infiltration and runoff rate of 5 mm/day is occurring at all channel nodes. A maximum run-on rate of 690 mm/day occurs for the node at the mouth of the watershed (the last node listed in the output file). The run-on rates are variable across model nodes, with increments of 10 mm/day for upland nodes and 5 mm/day for channel nodes. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file.	✓	
Test 4D: Infiltration, Net Infiltration, and Coupled Surface Water Flow Routing				
4D.1.	The results in the daily output file Test4d.v21 indicate that both runoff and run-on occur following all storm events. Runoff is always greater than run-on because some run-on always infiltrates at downstream nodes. (RD requirements 1, 6, 7, 8, 11, 12, 13)	Review file.	✓	
4D.2.	The results in the daily output file Test4d.v21 indicate that infiltrated run-on (run-infil) is always greater following winter storm events (day 2 of each year) compared to infiltrated run-on following summer storm events (day 201 of each year). Infiltrated run-on following the first storm event (day 2 of the simulation) is approximately 120 mm. Infiltrated run-on following all subsequent winter storm events (day 2 of each year) is approximately 25 mm. Infiltrated run-on following all summer storm events (day 201 of each year) is approximately 4.2 mm. (RD requirements 1, 6, 7, 8, 11, 12, 13)	Review file.	✓	
4D.3.	The results in the daily output file Test4d.v21 indicate that the amount of precipitation infiltrating directly into the root zone profile (as indicated by the increase in the del-soil term) is greater during winter storms. Direct infiltration of precipitation during the first storm event (day 1 of the simulation) is approximately 120 mm. Direct infiltration of precipitation during all subsequent winter storm events (day 1 of each year) ranges from approximately 69 mm to approximately 68 mm. Direct infiltration of precipitation during all subsequent summer storm events (day 200 of each year) ranges from approximately 44 mm to approximately 43 mm. (RD requirements 1, 6, 7, 8, 11, 12, 13)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4D.4.	The results in the daily output file Test4d.v21 indicate that from day 2 on, net infiltration occurs for all remaining days of the simulation. During 1980 and 1981 storm events, the net infiltration rate is approximately 0.15 mm/day for all days when net infiltration occurs. Following the 1982 summer storm event (day 201), the maximum net infiltration rate increases to approximately 0.75 mm/day for several days immediately following summer storm events and for several weeks immediately following winter storm events. Following the 1984 summer storm event (day 201), the maximum net infiltration rate increases to 1 mm/day for several days immediately following summer storm events and for several weeks immediately following winter storm events. (RD requirements 6, 7, 8, 10, 11, 12, 13)	Review file.	✓	
4D.5.	1.) The results in the average annual map file Test4d.v24 indicate that the average annual precipitation rate is variable across model nodes and ranges from a maximum of approximately 1156 mm/year to a minimum of approximately 1086 mm/year. The infiltrated run-on rate (run-infil) ranges from a minimum of 0 at upland nodes along the watershed divide (nodes with shallow soils and 0 upstream nodes, as indicated by the parameters in Test4d.v22 (totout) to a maximum of approximately 109 mm/year for the node at the mouth of the watershed (the last node listed in the output file). All upland nodes along the watershed divide have a uniform net infiltration rate of approximately 13 mm/year. All upland nodes affected by surface water run-on have a uniform net infiltration rate of approximately 62 mm/year. (2) All channel nodes have a uniform net infiltration rate of approximately 365 mm/year. (RD requirements 2, 6, 7, 8, 10, 11, 12, 15)	1.) Review file Test4d.v24. (refer to file Test4d.v22 to identify upland nodes). 2.) Review file Test4d.v24 (refer to file test4d.v26 to identify channel nodes; these are lines 25, 34, 43, 45, 53, 62, 68, 71, 73, 74, and 75).	✓ ✓	
4D.6.	The results of the daily map file for day 1 of the simulation (test4d1.v22) indicates that net infiltration has not been initiated in direct response to precipitation (net infiltration is 0 at all nodes). However, the water contents for all channel nodes indicates a fully saturated root zone profile (30 mm for layer 1, 270 mm for layer 2, 1500 mm for layer 3). All upland nodes along the watershed divide have a uniform layer 2 water content of approximately 142 mm, while upland nodes affected by run-on have a higher layer 2 water content of approximately 185 mm. Runoff is 0 at all channel nodes, while for upland nodes runoff ranges from a minimum of approximately 485 mm to a maximum of approximately 516 mm. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file. Refer to Test4D.5 for explanation of upland and channel nodes.	✓	
4D.7.	The results of the daily map file for day 2 of the simulation (test4d2.v22) indicates that for all channel nodes the layer 1 water content has decreased to 29 mm, and net infiltration is 1 mm. The layer 2 and 3 water contents remains at full saturation (270 mm for layer 2, 1500 mm for layer 3) at all channel nodes. For upland nodes along the watershed divide, water contents for the two soil layers remain unchanged relative to day 1. For upland nodes affected by run-on, the layer 2 water content has decreased to the field capacity water content of 180 mm, while the layer 4 water content has increased to approximately 5 mm (the soil layer has drained into the rock layer). The layer 1 water content for all upland nodes is at the field capacity water content of 20 mm. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file. (Refer to file test4d.v26 for field capacity and cdepth of layers to estimate field capacity water content.)	✓	
4D.8.	The results of the daily map file Test4d3.v22 for day 931 (day 200, 1982) indicates that the root zone is fully saturated at all channel nodes, and net infiltration of 1 mm is occurring in direct response to precipitation. Net infiltration is 0 at all upland nodes, and runoff has been generated at all nodes, including channel nodes. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4D.9.	1.) The results of the daily map file Test4d4.v22 for day 932 (day 201, 1982) indicates that for upland nodes affected by surface water run-on, water from soil layer 2 has drained into the rock layer (this is indicated by a comparison of results between day 931 and 932). The rock layer water content is at the effective storage capacity water content of 250 mm, and net infiltration is 1 mm. (2) For upland nodes along the watershed divide, the bottom soil layer has also drained into the rock layer, but net infiltration is 0 because the water content of the rock layer is below 250 mm. Net infiltration of 1 mm has occurred at all channel nodes, and the water content of the top soil layer has decreased from 30 to 29 mm. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1.) Review files Test4d4.v22 and test4d3.v22. 2.) Review file Test4d4.v22.	✓ ✓	
4D.10	The results of the daily map file Test4d5.v22 for day 1661 (day 200, 1984) indicates a net infiltration rate of 1 mm/day in response to infiltrated precipitation for all nodes except upland nodes along the watershed divide not affected by surface water run-on. For upland nodes affected by run-on, water contents of the two soil layers are above the field capacity water contents (20 mm for layer 1, 180 mm for layer 2), but below the full-saturation water contents (30 mm for layer 1, 270 mm for layer 2). Runoff is being generated at all model nodes. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review files Test4d5.v22. Refer to file Test4d5.v26 for field capacity and soil porosity used to calculate field capacity water content and full-saturated water content.	✓	
4D.11	The results of the daily map file Test4d6.v22 for day 1662 (day 201, 1984) indicates a net infiltration rate of 1 mm/day at all model nodes. For upland nodes not affected by surface water run-on, drainage from the bottom soil layer into the rock layer has increased the rock layer water content to 250 mm, allowing net infiltration to occur at the maximum rate defined by the bedrock bulk saturated hydraulic conductivity of 1 mm/day. The water content of the top soil layer for all upland nodes is at the field capacity water content of 20 mm. The water content of the second soil layer for all upland nodes is above the field capacity water content of 180 mm but below the full saturation water content of 270 mm. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file.	✓	
4D.12	1.) Comparison of results between the daily map file for day 1662 (Test4d6.v22) and 1668 (Test4d7.v22) indicates a uniform decrease in the root zone water content of 6 mm for all nodes affected by surface water run-on (refer to Test4d5.v22), corresponding to a net infiltration rate of 1 mm/day at these nodes. (2) For upland nodes not affected by surface water run-on, the decrease in water content is slightly less than 6 mm, and the net infiltration rate for day 1668 is slightly less than 1 mm/day. The bottom root zone layer is at the full-saturation water content for all nodes (layer 4 has 250 mm for upland nodes, layer 3 has 1500 mm for channel nodes). The water content of the top soil layer is at the field capacity water content of 20 mm for all upland nodes, and 23 mm for all channel nodes. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1.) Review files Test4d6.v22 and Test4d7.v22. 2.) Refer to file Test4d7.v22	✓ ✓	
Test 4E: Infiltration, Net Infiltration, Evapotranspiration, and Coupled Surface Water Flow Routing				
4E.1.	For the first day of the simulation, the results in the daily output file Test4e.v21 indicate an increase in root zone water content of approximately 103 mm, a runoff amount of approximately 457 mm, and outflow (run-on) from the watershed of approximately 369 mm. Evapotranspiration is approximately 3.5 mm on the first day, and net infiltration is 0 mm. (RD requirements 6, 7, 8, 9, 10, 11, 12, 13)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4E.2.	For the second day of the simulation, the results in the daily output file Test4e.v21 indicate that approximately 87.5 mm of run-on has infiltrated into the root zone. There is a net increase of approximately 69.5 mm in the root zone water content, and the net infiltration rate is approximately 14.7 mm/day. The evapotranspiration rate has decreased to approximately 3.35 mm/day. (RD requirements 6,,7, 8, 9, 10, 11, 12, 13)	Review file.	✓	
4E.3.	The results provided in the daily output file Test4e.v21 indicate that, with the exception of the last summer storm occurring on day 2027, the net infiltration rate is 0 for all summer storms (precipitation occurring on day 200 of each year). Infiltrated run-on is approximately 14.6 mm following all summer storms, which is less then the infiltrated run-on of approximately 87 to 86 mm following all winter storms. (RD requirements 6, 7, 8, 10, 11, 12, 13)	Review file.	✓	
4E.4.	The results provided in the average annual map file Test4e.v24 indicate that the average annual evapotranspiration rate is 0 for upland nodes along the watershed divide, approximately 144 mm/year for upland nodes with 1 to 4 upstream nodes, and approximately 330 mm/year for channel nodes. The average annual net infiltration rate is approximately 0.8 mm/year for upland nodes along the watershed divide, approximately 0.2 mm/year for upland nodes having 1 to 4 upstream nodes, and approximately 626 mm/year at all channel nodes. (RD requirements 2, 6, 7, 8, 9, 10, 15)	Review files Test4E.v24, T1c.W20 (to identify upstream nodes), and Test4e.v26 to identify channel and upland nodes. (See file "Test4E additional" created for convenience.) Watershed divide nodes "0" depth: 1through 7; 23, 29 through 31, 35, 37, 38, 42, 44 48, 50, and 52. Channel nodes: 25, 34, 45, 53, 62, 68, 71, 73 through 75.	✓	
4E.5.	1) The results provided in the daily map file for day 1 of the simulation (Test4e1.v22) indicate that net infiltration is 0 mm at all nodes. Thus, net infiltration has not been initiated in direct response to precipitation rates ranging from a maximum of approximately 578 mm/day to a minimum of approximately 543 mm/day. (2) The water content of the rock layer (layer 4) is 5 mm for all upland nodes having no soil cover, and this agrees with the 12-hour maximum infiltration capacity defined by the bedrock bulk saturated hydraulic conductivity of 10 mm/day. For channel nodes, the water contents of the first and second soil layers are at the field capacity water contents (20 mm for layer 1, 180 mm for layer 2), while the water content of the third soil layer is greater than the field capacity water content (1000 mm). (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1.) Review file Test4e1.v22. 2.) Review files Test4e1.v22 and Test4e.v26 for cdepth and field capacity values to calculate field water content.	✓ ✓	
4E.6.	1) The results provided in the daily map file for day 1 of the simulation (Test4e1.v22) indicate that total outflow of surface water form the watershed is equal to approximately 27690 mm. This is calculated as the sum of the runoff and run-on for the node at the mouth of the watershed (approximately 96 mm runoff plus 27594 mm run-on, as indicated for the last node listed in Test4e1.v22). The total outflow divided by the number of active model nodes (75) equals the average daily run-on term in the daily output file Test4e.v21 (approximately 369.2 mm). (2) The daily mean discharge rate calculated using the total outflow provided in Test4e1.v22 is approximately 10.2 cubic-feet-per-second, and this agrees with the two discharge rates provided in the daily output file (Test4e.v21). (RD requirements 2, 6, 7, 8, 9, 10, 11, 12, 16)	1.) Review file. 2.) See Attachment A2-1, Conversions.	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4E.7.	Results provided in the daily map file for day 1828 (Test4e7.v22) indicate that net infiltration is occurring in direct response to precipitation at upland nodes with no soil cover and at all channel nodes. Net infiltration at upland nodes with no soil cover is approximately 4.2 mm/day, and net infiltration at all channel nodes is 100 mm/day. Precipitation ranges from a maximum of approximately 578 mm at the highest elevation node (the first node listed in the output) to a minimum of approximately 543 mm at the lowest elevation node (the last node listed). The water contents of the soil layers for all channel nodes are at the full saturation water contents of 30 mm for layer 1, 270 mm for layer 2, and 1500 mm for layer 3. The layer 4 water content for upland nodes with soil cover is slightly less than the effective storage capacity of 25 mm. (RD requirements 2, 6, 7, 8, 9, 10, 16)	Review file.	✓	
4E.8.	Results provided in the daily map file for day 1829 (Test4e8.v22) indicate that net infiltration has stopped at all upland nodes along the watershed divide (nodes with no soil cover). The water content of layer 4 for these nodes is exactly 30 mm. (RD requirements 2, 6, 7, 8, 10, 16)	Review file Test4e8.v22. See file test4e.v26 for cdepth.	✓	
4E.9.	1) Results provided in the daily map file for day 1829 (Test4e8.v22) indicate a net infiltration rate of 1 mm/day for all upland nodes with 1 to 4 upstream nodes (and 1 meter soil cover), in response to infiltrated run-on from the storm of the previous day. (2.) The water content of layer 4 for these nodes is at the effective storage capacity water content of 25 mm, but the water contents of the two overlying soil layers are below the field capacity water contents of 20 mm for layer 1 and 180 mm for layer 2. (RD requirements 2, 6, 7, 8, 10, 11, 16)	1.) Review file Test4e8.v22. and T1c.W20 (See file "Test4E additional" created for convenience.) 2.) Review file Test4e8.v22.	✓ ✓	
4E.10.	Results provided in the daily map file for day 1829 (Test4e8.v22) indicate soil layers 1 and 2 have drained into soil layer 3 at all channel nodes. This is indicated by water contents for the upper soil layers that have decreased from full saturation to slightly below the field capacity water contents. The layer 3 water content has remained at approximately 1500 mm (full saturation), even though net infiltration of 100 mm has occurred at all channel nodes. (RD requirements 2, 6, 7, 8, 9, 10, 11, 16)	Review file.	✓	
4E.11.	Results provided in the daily map file for day 2027 (Test4e9.v22) indicate that net infiltration of approximately 0.83 mm has occurred at upland nodes with no soil cover. The infiltration rate is consistent with the maximum infiltration capacity for a summer storm and a bedrock bulk saturated hydraulic conductivity of 10 mm/day (10*(2/24) = 0.8333). Net infiltration is 0 at all other model nodes. (RD requirements 2, 6, 7, 8, 9, 10, 11, 16)	Review file. See file test4e.v26 for bedrock ks = 10mm/dy. See Infilv2.for for summer storm duration = 2 hours, recognizing 2/24 is the fraction of the day for storm input.	✓	
4E.12.	Results provided in the daily map file for day 2028 (Test4e0.v22) indicate that net infiltration has not occurred in response to infiltrated run-on. The layer 2 water content is below the field capacity water content of 180 mm at all nodes, and thus there has been no drainage of water through the second soil layer. (RD requirements 2, 6, 7, 8, 9, 10, 11, 16)	Review file.	✓	
Test 4F: Infiltration, Net Infiltration, Evapotranspiration, and Coupled Surface Water Flow Routing				
4F.1.	Comparison of results in the daily output files for test 4f (Test4f.v21) and test 4e (Test4e.v21) indicates that runoff, run-on, and infiltrated run-on are slightly higher per storm event for test case 4f relative to 4e. The total runoff for test 4f is approximately 6045 mm, compared to approximately 5923 mm for test 4e. The total run-on for test 4f is approximately 5433 mm, compared to approximately 5316 mm for test 4e. (RD requirements 1, 6, 7, 8, 9, 10, 11, 13)	Review files Test4f.v21 and Test4e.v21. Confirm parameter relationships using spreadsheet summation function. Refer to file, column AB for summations using spreadsheet function.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4F.2.	1.) Comparison of results in the daily output files for test 4f (Test4f.v21) and test 4e (Test4e.v21) indicates that net infiltration during winter storm events is lower for test 4f compared to test 4e. Starting in 1981, net infiltration on day 1 of each year is approximately 2.3 to 2.6 mm for test 4f, compared to approximately 14.7 to 15.7 mm for test 4e. For test 4f, net infiltration is 0 for the last summer storm event in 1985, compared to 0.2 mm for test 4e. (2) Total net infiltration for test 4f is approximately 361 mm, compared to approximately 552 mm for test 4e. (RD requirements 6, 7, 8, 9, 10, 11, 13)	1.) Review and compare files Test4f.v21 and Test4e.v21. 2.) Sum and compare total net infiltration.	✓ ✓	
4F.3.	Comparison of results in the daily output files for test 4f (Test4f.v21) and test 4e (Test4e.v21) indicates that the maximum evapotranspiration rate in response to each storm event is lower for test 4f compared to test 4e. Maximum evapotranspiration for test 4f is less than 3 mm/day for winter storms and less than 1 mm/day for summer storms, whereas for test 4e maximum evapotranspiration is greater than 3 mm/day for both winter and summer storms. Total evapotranspiration for the entire simulation, however, is greater for test 4f (approximately 920 mm) relative to test 4e (approximately 808 mm). (RD requirements 6, 7, 8, 9, 10, 11, 13)	Review files Test4f.v21 and Test4e.v21. Maximum summer storm is day 200 of every year. Maximum winter storm is day 1 of each year. Refer to file, column AB for summation of evapotranspiration using spreadsheet function.	✓	
4F.4.	Results provided in the average annual map file Test4f.v24 indicate that the average annual evapotranspiration rate is approximately 5.8 mm/year for upland nodes along the watershed divide, approximately 115 mm/year for upland nodes with 1 to 4 upstream nodes, and approximately 566 mm/year for channel nodes. The average annual net infiltration rate is 0 mm/year for all upland nodes, and approximately 410 mm/year at all channel nodes. (RD requirements 6, 7, 8, 9, 10, 11, 15)	Review file Test4f.v24. Refer to Test4E4 for node identification (tests use same geospatial input, T1c.W20).	✓	
4F.5.	1.) Results provided in the daily map file for day 1 of the simulation (Test4f1.v22) indicates that net infiltration has not been initiated in direct response to precipitation (net infiltration is 0 at all nodes). The water content of the rock layer (layer 4) is 0 for all upland nodes having 1 meter of soil cover (upland nodes downstream of the watershed divide). (2) The water content of the rock layer for upland nodes on the watershed divide is approximately 4.2 mm, which is less than the water contents of 5 mm obtained for test 4e on day 1. (RD requirements 2, 6, 7, 8, 10, 16)	1.) Review file. 2.) Review and compare files Test4f1.v22 and Test4e1.v22.	✓ ✓	
4F.6.	1.) Results provided in the daily map file for day 1 of the simulation (Test4f1.v22) indicate that total outflow of surface water form the watershed is equal to approximately 27934 mm. This is calculated as the sum of the runoff and run-on for the node at the mouth of the watershed (approximately 100 mm runoff plus 27834 mm run-on, as indicated for the last node listed in Test4f1.v22). The total outflow divided by the number of active model nodes (75) equals the average daily run-on term in the daily output file Test4f.v21 (approximately 372.4 mm). (2) The daily mean discharge rate calculated using the total outflow provided in Test4f1.v22 is approximately 10.3 cubic-feet-per-second, and this agrees with the discharge rate provided in the daily output file (Test4f.v21). (RD requirements 2, 6, 7, 8, 9, 10, 11, 12, 13, 16)	1.) Review file. 2.) See Attachment A2-1, Conversions	✓ ✓	
4F.7.	1.) Results provided in the daily map file for day 2 (Test4f2.v22) indicate uniform net infiltration rates of 100 mm/day at all channel nodes. (2) The layer 4 water content for all upland nodes is approximately 3.6 mm (this is less than the layer 4 water contents of approximately 4.4 mm obtained for test 4e (Test4e2.v22) on day 2). (RD requirements 2, 6, 7, 8, 10, 16)	1.) Review file. Refer to Test4E4 for node identification (tests use same geospatial input, T1c.W20). 2.) Review and compare files Test4f2.v22 and Test4e2.v22.	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4F.8.	Results provided in the daily map file for day 4 of the simulation (Test4f4.v22) indicate a uniform net infiltration rate of approximately 61 mm/day at all channel nodes, which is less than the results obtained for test 4e. The layer 4 water contents at upland nodes range from approximately 2.4 to 2.5 mm, compared to water contents ranging from 4 to 5 mm obtained for test 4e. The layer 1 water content is 20 mm at all nodes with a soil thickness of 1 or 6 meters, compared to a layer 1 water content of approximately 12 mm for test 4e. (RD requirements 2, 6, 7, 8, 10, 16)	Review and compare files Test4f4.v22 and Test4e4.v22.	✓	
4F.9.	Results provided in the daily map file for day 1828 (Test4f6.v22) indicate net infiltration rates (in direct response to precipitation) of 0 mm/day at all upland nodes and approximately 17 mm/day at all channel nodes. These net infiltration rates are much lower than results obtained for test 4e (Test4e7.v22), which include a net infiltration rate of 100 mm/day at all channel nodes. (RD requirements 2, 6, 7, 8, 10, 16)	Review file Test4f6.v22 and compare with file Test4e7.v22.	✓	
4F.10.	Results provided in the daily map file for day 1828 (Test4f6.v22) indicate water contents for layer 4 at all upland nodes are less than 5 mm, compared to water contents of 22 to 30 mm for test 4e (Test4e7.v22). For test 4f, the water contents of the first and second soil layer at channel nodes are at the field capacity water contents (20 mm for layer 1, 180 mm for layer 2), while the water content of soil layer 3 is approximately 1431 mm. These water contents show a drier root zone profile compared to results obtained for test 4e, which show a fully saturated root zone profile at channel nodes for day 1828. (RD requirements 2, 6, 7, 8, 16)	Review file Test4f6.v22 and compare with file Test4e7.v22.	✓	
4F.11.	1.)Results provided in the daily map file for day 1829 (Test4f7.v22) indicate that the upland nodes with no soil cover have dried relative to day 1828 due to transpiration (the layer 4 water content at all nodes has decreased from approximately 4.2 to 3.6 mm). The layer 4 water content for upland nodes with 1 meter soil cover has increased from approximately 0.007 to 22.3 mm due to drainage from soil layer 2, which still has a water content slightly higher than the field capacity water content of 180 mm. (2) These results are in contrast to results obtained for test 4e (Test4e8.v22), which show the soil layers having water contents slightly less than the field capacity water contents, and a layer 4 water content equal to the effective storage capacity of 25 mm. (RD requirements 2, 6, 7, 8, 9, 16)	`1.)Review and compare files Test4f6.v22 and Test 4f7.v22. 2.) Review and compare files Test4f7.v22 with Test4e8.v22.	✓ ✓	
4F.12.	Results provided in the daily map file for day 1829 (Test4f7.v22) indicate that net infiltration is not occurring at upland nodes, while for test 4e (Test4e8.v22) a net infiltration rate of 1 mm/day occurs at all upland nodes with 1 meter soil cover. Both tests indicate a uniform net infiltration rate of 100 mm/day at all channel nodes, but layer 3 is very close to full saturation (water content of 1500) for test 4e, while layer 3 is drier for test 4f (water content of approximately 1329 mm). For test 4f, the water content for layer 1 remains at the field capacity water content (20 mm) for all nodes with soil cover. The differences in results between the 2 tests are consistent with the differences in the specified root densities for the two tests. (RD requirements 2, 6, 7, 8, 10, 16)	Review and compare files Test4f7.v22 with Test4e8.v22.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4F.13.	Results provided in the daily map file for day 2027 (Test4f9.v22) indicate that net infiltration is not occurring in response to precipitation during the final summer storm event in the simulation period. This result is in contrast to results obtained for test 4e (Test4e9.v22), which shows the occurrence of net infiltration at upland nodes with no soil cover. For test 4f, the layer 4 water content at all upland nodes is only slightly greater than 0, as compared to results for test 4e which show water contents that are at the effective storage capacity water contents of 25 and 30 mm for upland nodes. (RD requirements 2, 6, 7, 8, 10, 16)	Review and compare files Test4f9.v22 and Test4e9.v22.	✓	
Test 5A: Snow Cover Accumulation				
5A.1.	Results provided in the daily output file Test5a.v21 indicate that all precipitation occurred as snow, with snowfall = precipitation = 1 mm/day for all days simulated. Total precipitation equals total snowfall, which equals 2192 mm. The snow-cover term on the final day of the simulation (day 2192) equals 2192 mm. All remaining water balance terms are 0. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5A.2.	Results provided in the daily output file Test5a.v21 indicate that potential evapotranspiration, and thus sublimation, is 0 for all days simulated. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5A.3.	Results provided in the daily output file Test5a.v21 indicate the daily air temperature is a constant –49.3 C for all days simulated (the –50 C input value is adjusted for elevation). (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5A.4.	The average annual map file (Test5a.v24) indicates a precipitation rate and snowfall rate of 365.25 mm/year, and an average annual snow cover term of approximately 400496 mm/year (although this term has no physical meaning, it is used as part of the validation for water balance calculations). All remaining terms in the average annual map file are 0. (RD requirements 4, 5, 7, 8, 15)	Review file.	✓	
Test 5B: Sublimation				
5B.1.	Results provided in the daily output file Test5b.v21 indicate that all precipitation occurred as snow. Snowfall and precipitation are equal to 1 mm/day for all days simulated. Total precipitation and snowfall of 2192 mm is greater than the snow-cover term of approximately 2000 mm on the final day of the simulation, because some of the snow has been lost to sublimation. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5B.2.	Results provided in the daily output file Test5b.v21 indicate that potential evapotranspiration is greater than 0 for all days simulated. Sublimation occurs as a fraction of potential evapotranspiration, and thus is also greater than 0 for all days simulated. Potential evapotranspiration ranges from a minimum of approximately 0.3 mm/day to a maximum of approximately 1 mm/day, while sublimation ranges from a minimum of approximately 0.04 mm/day to a maximum of approximately 0.13 mm/day. (RD requirements 3, 4, 5, 6, 7, 8, 13)	Review file.	✓	
5B.3.	Results provided in the daily output file Test5b.v21 indicate that daily air temperature is a constant –9.3 degrees C for all days simulated (the –10 C input value is adjusted for elevation). (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5B.4.	Results provided in the daily output file Test5b.v21 indicate that excluding precipitation, snowfall, snow-cover, sublimation, and potential evapotranspiration, all other daily water balance terms are 0, and the daily water balance check is satisfied for all days simulated. (RD requirements 3, 4, 5, 6, 7, 8, 13)	Review file. Refer to Attachment A2-1, Item 14 for Equation 2.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
5B.5.	Results provided in the average annual map file (Test5b.v24) indicates a precipitation rate equal to the snowfall rate of 365.25 mm/year for all model nodes. (RD requirements 4, 5, 6, 7, 8, 15)	Review file.	✓	
5B.6.	Results provided in the average annual map file (Test5b.v24) indicate that snow-cover and sublimation are variable across model nodes, even though precipitation and snowfall are uniform. Average annual sublimation rates range from a minimum of approximately 29 mm/year to a maximum of approximately 36 mm/year. The variability is due to the combined effects of variability in potential evapotranspiration in response to topographic effects on shading, sun-angle, and intensity of incoming solar radiation, and variability in air temperature as a function of elevation. (RD requirements 3, 4, 5, 6, 7, 8, 15)	Review file.	✓	
5B.7.	Results provided in the average annual map file (Test5b.v24) indicate that except for precipitation, snowfall, snow-cover, and sublimation, all remaining terms in the average annual map file are 0, and the water balance is satisfied for all model nodes. (RD requirements 3, 4, 5, 6, 7, 8, 15)	Review file. Refer to Attachment A2-1, Item 14 for Equation 2.	✓	
Test 5C: Snowfall and Snow Cover Distribution				
5C.1.	Results provided in the daily output file Test5c.v21 indicate a constant daily precipitation rate of 2 mm/day, with approximately 1.25 mm/day occurring as rain and 0.75 mm/day occurring as snow. Average daily air temperature is constant at 0.1 degrees C. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5C.2.	Results provided in the daily output file Test5c.v21 indicate that potential evapotranspiration, actual evapotranspiration, and sublimation are variable through time. Potential evapotranspiration ranges from a minimum of approximately 0.48 mm/day to a maximum of approximately 1.5 mm/day. Sublimation ranges from a minimum of approximately 0.02 mm/day to a maximum of approximately 0.07 mm/day, and evapotranspiration ranges from a minimum of approximately 0.19 mm/day to a maximum of approximately 0.86 mm/day. (RD requirements 3, 4, 5, 6, 7, 8, 13)	Review file.	✓	
5C.3.	Results provided in the daily output file Test5c.v21 indicate that total snow-cover on the last day simulated is approximately 1529.2 mm, which is less than the total snowfall of approximately 1636.7 mm because of sublimation. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5C.4.	Results provided in the daily output file Test5c.v21 indicate that snowmelt is 0 for all days simulated. Infiltrated run-on (run-infil) is 0 for the first 369 days simulated. Net infiltration ranges from a maximum of approximately 0.5 mm/day to a minimum of 0. (RD requirements 4, 5, 6, 7, 8, 9, 10, 11, 13)	Review file.	✓	
5C.5.	Results provided in the average annual map file (Test5c.v24) indicate that the average annual net infiltration rate is 0 for the first 28 model nodes (these nodes are all at higher elevation than the remaining model nodes). For the remaining model nodes (nodes 29 through 75), all precipitation occurs as rain (at a rate of 730.5 mm/year) and the net infiltration rate ranges from a maximum of 249 mm/year to a minimum of 225 mm/year. The average annual snowmelt and infiltrated run-on rates (run-infil) are 0 at all nodes. For nodes 1 through 28, all precipitation occurs as snow, and with the exception of the snow-cover and sublimation terms, all other components of the water balance are 0. (RD requirements 3, 4, 5, 6, 7, 8, 9, 10, 11, 15)	Review File.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
Test 5D: Spatial and Temporal Distribution of Snowfall and Snow Cover				
5D.1.	Results provided in the daily output file Test5d.v21 indicate a constant daily snowfall rate of 2 mm/day from day 293 through day 105 of the following year, and a corresponding rainfall rate of 0 mm/day. From day 105 through day 109 of each year, snowfall is reduced from 2 mm/day to 0 mm/day while rain is increased from 0 mm/day to 2 mm/day. From day 109 through day 289 of each year, the rainfall rate is constant at 2 mm/day while the snowfall rate is 0 mm/day. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5D.2.	Results provided in the daily output file Test5d.v21 indicate that starting on day 290 of each year except 1980, the snow-cover term shows an accumulating snow pack with a maximum snow pack depth (water equivalent) of approximately 354 to 356 mm (depending on leap year) on day 107 of the following year. From day 108 through day 142, the snow-cover term shows a continuous decrease to 0 mm in response to melting. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5D.3.	Results provided in the daily output file Test5d.v21 indicate a sublimation rate greater than 0 for all days having snow-cover greater than 0. The sublimation rate shows an increase from approximately 0.16 mm/day to more than 0.7 mm/day during the onset of snow-melt and transpiration from the root zone underlying the snowpack. As the air temperature increases to above freezing, the snow-melt term increases from 0 to a maximum rate of approximately 18 to 19 mm/day on day 138 of each year except 1980. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5D.4.	Results provided in the daily output file Test5d.v21 indicate that with the exception of 1980, runoff and run-on are initiated in response to snow melt on day 123 of each year. Run-on is less than runoff for all days on which runoff occurs because surface water is allowed to infiltrate into the root zone. (RD requirements 4, 5, 6, 7, 8, 11, 13)	Review file.	✓	
5D.5.	Results provided in the daily output file Test5d.v21 indicate that with the exception of 1980, net infiltration is initiated on day 106 of each year in response to the combined onset of snowmelt and precipitation occurring as rain. After the period of snowmelt, net infiltration decreases in response to increasing evapotranspiration, then increases as potential evapotranspiration rates decrease with the onset of winter. A maximum net infiltration rate of 1 mm/day occurs on day 293 of each year (except 1980) because evapotranspiration decreases to 0 as air temperature drops below freezing. (RD requirements 4, 5, 6, 7, 8, 9, 10, 13)	Review file.	✓	
5D.6.	Results provided in the average annual map file (Test5d.v24) indicate variable average annual net infiltration rates ranging from a maximum of approximately 147 mm/year to a minimum of approximately 124 mm/year. With the exception of the run-infil and the run-on terms, all components of the water balance are greater than 0 at all nodes, and all components of the water balance show variability across model nodes in response to topographic effects (elevation, blocking ridges, and surface water routing). (RD requirements 3, 4, 5, 6, 7, 8, 9, 10, 11, 15)	Review file.	✓	

Attachment A2-1: Additional information and examples

Background Information

Conversions

i.) mm/day to cfs:

Totout in the output refers to run-on depth, in mm. To compare *.v21 with *.v22, find the sum of the totout + run-off terms in *.v22 at the watershed pour-point cell (last node), convert metric to English, and convert rate to cubic-feet-per-second to compare this value with the discharge value in test0a.v21.

$$\text{cfs} = (\text{mm/day}(\text{grid cell area in m}^3)\ (35.31\ \text{ft}^3))\ /\ ((1000)(24)(60)(60))$$

ii.) Average daily run-on term: The total outflow of surface water form the watershed is equal the sum of the runoff and run-on for the node at the mouth of the watershed (the last node listed in the ".v22" file. The total outflow divided by the number of active model nodes (75) equals the average daily run-on term in the daily output file ".v21". The daily mean discharge rate calculated using the total outflow provided is converted to cubic-feet-per-second, and this agrees with the two discharge rates provided in the daily output file ".v21".

Common Parameters

(Layer thickness is reported as cdepth in meters; the following properties are reported in millimeters)

rkmm = effective bedrock storage capacity = rkpor*cdepth(4,ia)*1000.

scapmm ; soil storage capacity = ((soilporo - soilresid) x cdepth x 1000.)

Example from test1b.v22:

scapmm3	soilmm(3)	soilresid	cd3	soilporo
117.6	112	0.028	0.4	0.322

scapmm3 = (.322 - .028)(.4)(1000) = 117.6

fcmm = soil field capacity = (fc x cdepth x 1000)

soil field capacity = (fc x cdepth x 1000) = 0.2 x 0.3 x 1000

soilmm = soil water content= full saturated water content = (soilporo x depth x 1000)

Example from Test3F.6

soilmm = soil water content= **full saturated water content**

= (soilporo x depth x 1000)

= 0.3 x 0.7 x 1000

= 210

Clarification and Comment

i.) Test "v" output files:

Column labels for test sequence output files were not included in all test output files designated as "v". A guide to these columns is provided in this attachment. Additionally, all test case output files were converted to EXCEL files with labeled columns.

The program run results correctly produce the required output, "v" files for all test cases; however, the file names for some files in the Summary Statistic file differs from that in the INFILv2.CTL file, and the output files identified in the Validation Test Report (VTR) or Requirements Document (RD). The files are identified in the INFILv2.CLT files as follows:

test0a.v21	dayall: (RD: Average daily output/mass balance terms)
test0a.v22	ndaymap, (RD: 24-hour mass balance map)
test0a.v23	daily mass balance (RD: Annual summary/Summary statistics file)
test0a.v24	total daily fluxes (RD: Average annual map output;VTP: Daily output file)
test0a.v25	annual mass balance terms (RD: Secondary daily output)
test0a.v26	new debug file (RD: Root zone layer parameter output)

The Summary Statistics output file identifies the files as follows:

Average daily mass balance terms	test0a.v21
24-hour mass balance map	test0a.v22
Annual mass balance map	test0a.1
Average annual mass balance map:	test0a.v24
Summary statistics output	test0a.v23
Debugging output	test0a.v25

The following example is a comparison of files with different names in the summary output file.

Annual mass balance map: test0a.1 is referred to as a test0a.v25 file.
Average annual mass balance map: test0a.v24 is referred to as test0a.v24.
Debugging output:test0a.v25 is referred to as test0a.v26.

The difference in file names does not impact the functionality of the program. The file names used in the Requirements Document are commonly used in the validation test report.

ii.) For test case criteria requiring verification of summation and simple statistics, the EXCEL version of the file under review includes the summation or statistic in the columns to the right of the data.

Common Parameter Definitions

aaprepx	average annual precip for area of potential repository
BARSOIL	bare soil et parameters
BSOIL (bsoil)	estimated or fitted parameter for relative proportion of total et at bare soil
depth and cdepth:	thickness of root zone (m)
discharge	cfs
drmm (1-4)	drmm1 = soilmm(1,ia)-fcmm1
easting and northing:	(m)
elevation:	(m)
et	evapotranspiration
fcmm(1)	fieldcp*cdepth(1,ia)*1000
fieldcap:	field capacity (m3/m3)
flow-in	sum of all run-on components (contribution from all cells) for a given grid cell
flow-out	surface water that leaves cell and continues downstream
fract-infil	net infiltration interms of fracture flow.
ifrtol	flow routing tolerence term
imbibe:	Ksat (mm/day)
imb2:	imbibe*(365.2)
infilmm(ia)	drmm4 + rinfmm2(ia)
IVEGC	invoke vegetation map cover in et calculation under certain conditions
iwat	downstream identification no.
idepth	(1 - 4); root zone parameter line index number;
petday	potential ET per day
petrsday	total potential ET per day
potis	initital condition water potential
pptloc	average daily precip for each grid cell
RDEPTH	root zone depth (1-4); index variable to associate root zone parameters to soil depth class IDPTH.
RTZA(B, C, and D)	estimated or fitted parameter for function defining root density as a function of depth
rockmm:	Initial rock water content (mm)
rkmm	effective bedrock storage capacity
rkmmfact	initial rock water content condition
run-infil	surface water flow infiltration
outflow	run-off from cell that is being routed to downstream cell (at the receiving cell, it is called run-on)
runoff (run)	water that has not been routed; water that accumulates in surface depressions and basins or contributes to surface water flow (which is routed to downstream locations as run-on)
run-on	flow depth being added to water budget of a cell; water that contributes to either infiltration or accumulated surface-water run-on at downstream locations.(see upstream node)
scapmm	storage capacity (mm)
SCAPMMT	total water storage capacity is the sum of the soil layers' capacities
SDFACT	soil depth scaling factor
skmm:	soil permeability (mm/day); saturated soil ksat (skmm)
sksfact	soil permeability scaling fact
ROCKRESID	(rockid), real m^3/m^3, ($0 \leq$ rockresid $\leq$ rockcap). Estimated or measured residual water content for evapotranspiration.
sl (slope):	measure from horizontal (degrees)

Common Parameter Definitions (cont'd)

soilmm	soil water content: soilvwc(ia)*cdepth(i,ia)*1000.
soilporo	soil porosity (m3/m3)
soilresid:	residual water (mm)
tetday	total annual ET
temperature	degrees centigrade
TotoutC	in the input refers to the number of upstream cells.
Totout	in the output refers to run-on depth, in mm.
upstream node	The surface water run-on depth is calculated as runoff generated and routed from upstream grid cells.
wilting point	soilporo -fieldcap

Explanations and Examples

1. Program Files

A. Test1A, Model Control File

```
INFILv2.ctl: INFIL v2.0 VTP test case 1a, run code t1-1a-v2-w20 (5/27/1999)
1                              OPTMASSB
0  0.00000001                      IROUT(1 = coupled, 0 = uncoupled, -1 = flow routing off, -2 = infil
off), IFRTOL
2  2    1.78                                   ISNOW, ISNWMOD, SNOPAR1
3  0.1  0.3                     ISUBLIM, SUBPAR1, SUBPAR2
0  1.                          IPPTTEST (1 for testing), PPTTEST = constant
0  .0                          IETTEST (1 for testing), ETTEST = constant
30.0                           CELSIZE (node spacing (meters): using for flow volume calculations)
544691.0 4074153.0                   xcfs,ycfs: coords for discharge cell
1980  1  1995   274     0   1        yr1 = start year, dnn1 = start day, yr2 = end year, dn2 = end day
0    0   0   0                 multipliers ( pptfact, etfact, imbfact, sksfact)
0.0  0   0.2                    SDFACT (soil depth multiplier), IVEGC (set to 1 for map data),
FVEGC (use if IVEGC = 0)
1.0  0.5  0.2   0.01               ROOTF1,ROOTF2,ROOTF3,ROOTF4
1.0  0.8  0.2   0.05               MAXWGT1, MAXWGT2, MAXWGT3, MAXWGT4
.30  1.5  2.0   2.0                RDEPTH1,RDEPTH2,RDEPTH3,RDEPTH4,RDEPTHF
0.0  1.0  .5                   RKPOR, RKMMFACT, FLAREA
1  1   0                       INFMOD, ETMOD, RUNMOD
-10.0  1.04                             BARSOIL1, BARSOIL2:  bare soil et parameters
1  17.3  11.74                    IAIRTEMP = 1 for new air temp model, ATEMP1 = avg. air temp,
ATEMP2 = air temp seasonal deviation
2                              HSTEP: time step for PET model (hours)
1  181  0                         PPTYUC (=5 diminished elev. correlation, =2 for 4JA , =1 for simple*
elevation transfer), AAPREPX, IPPTDAT
mod3-ppt.dat                       input file name:  daily precip
   0    1   0.5    1    1        dpthflag, irtz, delvwcf, moistcr, fracmod
   0     0.0                   IVWCFLG,   vwcfact
t1.w20                          input file name:  map parameters (*.inp)
-1
test1a.v21                        dayall: average daily mass balance terms
```

```
1   1                         ndaymap, imap
70  1995
testla.v22
testla.v23                       output file name:  daily mass balance
testla.v24                       output file name:  total daily fluxes
1     1                        dbgflag, dbgflag2
testla.v25                       output file name:  annual mass balance terms
0                            '  IDEBUG:  debugging option parameter
testla.v26                       new debug file
testla                         map output:  annual totals or mult-year averages
--
```

*The PPTYUC shown , PPTYUC = 5, and the corresponding value of "181" are only a place holders, relict comments from the original file. See Validation Test Plan (10307-VTP-2.0-00), Table A1 to confirm value used.

Model Control File (continued)

Parameters for dynamic root-zone function

	depth (m)	rtza	rtzb	rtzc	rtzd	bsoil	delvwc
4							
1	0.5	15	3	3	2	0.3	0.5
2	1.5	15	4	2	2	0.2	0.5
3	4.5	10	1.5	1	2	0.1	0.5
4	6	10	1.5	1	2	0.05	0.25

Soil Properties (Brooks & Corey/van Genuchten (combined)

	fdcp m^3/m^3	et	residpor m^3/m^3	beta	alpah 1/(J/Kg)	ksat Jsec/m^3	PE J/Kg	B	n	vg-alpha 1/(J/Kg)	sorp J sec/m^3	SOILP	potis J/Kg
10													
1	0.242	0.054	0.366	-2.5	1.26	5.60E-04	-1.19E+00	4.72	1.24	5.20E-01	0.39	0.05	-1.00E+02
2	0.173	0.023	0.315	-2.5	1.26	1.20E-03	-9.41E-01	3.7	1.31	6.20E-01	0.5	0.05	-1.00E+02
3	0.163	0.017	0.325	-2.5	1.26	1.30E-03	-8.60E-01	3.36	1.36	6.60E-01	0.51	0.05	-1.00E+02
4	0.073	0.002	0.281	-2.5	1.26	3.80E-03	-6.22E-01	2.18	1.62	8.70E-01	0.7	0.05	-1.00E+02
5	0.2	0.035	0.33	-2.5	1.26	6.70E-04	-1.07E+00	4.14	1.78	5.60E-01	0.4	0.05	-1.00E+02
6	0.15	0.011	0.339	-2.5	1.26	2.70E-03	-7.55E-01	3.06	1.4	7.40E-01	0.7	0.05	-1.00E+02
7	0.234	0.046	0.37	-2.5	1.26	5.60E-04	-1.10E+00	4.43	1.26	5.50E-01	0.39	0.05	-1.00E+02
8	0.234	0.046	0.37	-2.5	1.26	5.60E-04	-1.10E+00	4.43	1.26	5.50E-01	0.39	0.05	-1.00E+02
9	0.189	0.028	0.322	-2.5	1.26	5.70E-04	-1.08E+00	3.88	1.3	5.50E-01	0.37	0.05	-1.00E+02
10	0.189	0.028	0.322	-2.5	1.26	5.70E-05	-1.08E+00	3.88	1	5.50E-01	0.037	0.05	-1.00E+02

B. Example from geospatial input file: Partial input from test1bt1.w20 file

Grid Cell I.D.	UTM easting (m)	UTM northing (m)	latitude (degrees)	longitude (degrees)	row I.d.	column I.d.	down-stream grid cell I.d. no.	no. of up-stream cells	elevation (m)	slope (degrees inclined from horiz.	aspect (degrees from north)	soil-type I.d.
33982	547571	4077573	36.8447	116.4664	343	98	-3	0	1495	11	215	5
33983	547571	4077543	36.8444	116.4664	344	98	-3	0	1495	8	216	5
34190	547571	4077513	36.8441	116.4664	345	98	-3	0	1494	6	223	10
34379	547601	4077663	36.8455	116.4661	340	99	-3	0	1493	7	221	10
34380	547601	4077633	36.8452	116.4661	341	99	35414	0	1493	5	232	10
34381	547571	4077603	36.845	116.4664	342	98	-3	0	1493	13	210	5
34382	547601	4077603	36.8449	116.4661	342	99	35609	0	1493	5	85	5
34383	547601	4077573	36.8447	116.4661	343	99	36037	0	1493	8	95	5

(continuation of columns for eight rows shown)

soil depth (m)	rock-type I.d.	topo position I.d.	vegetation-type I.d.	percent vegetation cover	these and remaining 34 columns (not shown here) are 36 blocking-ridge angles	
1	0.48	314	4	3	30	1
1	0.46	314	5	3	30	1
1	0.42	314	5	5	30	1
1	0.44	314	5	3	30	1
1	0.4	314	6	3	30	1
1	0.45	314	4	3	30	1
1	0.4	314	6	3	30	1
1	0.46	314	4	3	30	1

C. Example of output files, ".v" with labeled columns:

Output file ".v.21" : The spatially average daily mass balance terms (see Requirements Document ,SDN 10307-RD-2.0-00):
file: DAYALL

day	year	mo	dy	day	temp	precip	rain	snow-fall	snow-cover	snow-melt	sublimation	pot-evaptrs	evapo-trans
1	1980	-9	-9	1	6.6	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.809904751	0.123161550
2	1980	-9	-9	2	6.6	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.817261934	0.118650811
3	1980	-9	-9	3	6.5	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.819999762	0.113509781
4	1980	-9	-9	4	6.5	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.823320038	0.108586165
5	1980	-9	-9	5	6.5	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.826980380	0.103852891
6	1980	-9	-9	6	6.4	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.830679657	0.099279188
7	1980	-9	-9	7	6.4	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.836783570	0.095151856

run-infil	del-soil	net-infil	runoff	run-on	fract-inf	it	discharge-#1	discharge-#2	mass-balance	mass-balance 2
0.000000000	-0.123161550	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	-.166533454E-15	0.00000000
0.000000000	-0.118650811	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	-.235922393E-15	0.00000000
0.000000000	-0.113509781	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	0.971445147E-16	0.00000000
0.000000000	-0.108586165	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	-.138777878E-16	0.00000000
0.000000000	-0.103852891	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	-.152655666E-15	0.00000000
0.000000000	-0.099279188	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	0.971445147E-16	0.00000000
0.000000000	-0.095151856	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	-.180411242E-15	0.00000000

Output file "v.22" : 24-hour mass balance map (see Requirements Document ,SDN 10307-RD-2.0-00):
file: DAYMAP

easting	northin	j	pptloc	soilmm	soilmm (1)	soilmm (2)	rockmm (3)	infilmm	run-off	totout
547601.0	4077633.0	5549	34.6944	96.4880	32.2000	0.0000	36.0000	3.3366	3.9404	0.0000
547601.0	4077603.0	5549	34.6944	98.8914	33.0000	0.0000	36.0000	3.3367	5.3632	0.0000
547601.0	4077573.0	5549	34.6944	96.3742	52.8000	0.0000	35.4000	3.3367	0.0000	0.0000
547601.0	4077543.0	5549	34.6720	93.6052	59.4000	0.0000	35.2000	3.3366	0.0000	0.0000
547631.0	4077693.0	5549	34.5826	93.6563	59.4000	0.0000	35.2000	3.3366	0.0000	0.0000
547631.0	4077663.0	5549	34.5826	90.9970	66.0000	0.0000	35.0000	3.3366	0.0000	0.0000

Output file "v.23" : Summary statistics file for spatially averaged variable(s) value

```
INFILv2.ctl: INFIL v2.0 VTP test 0a, run code t1-4ex-v2-w20 (5/27/1999)
 Daily precipitation input:                    mod3-ppt.dat
 Watershed modeling domain parameters:         t1.w20
 Average daily mass balance terms:             test0a.v21
 24-hour mass balance map:                     test0a.v22
 Annual mass balance map:                      test0a.1
 Average annual mass balance map:              test0a.v24
 Summary statistics output:                    test0a.v23
 Debugging output:                             test0a.v25

Total number of days read in    =     5753
 Total daily precip              =   2852.0
 Average annual precip (mm)      =    181.1
 Maximum daily precip (mm)       =     58.0

TOTAL NUMBER OF LOCATIONS      =      125
 AVERAGE ELEVATION OF SAMPLE   =   1453.2
 MAXIMUM ELEVATION OF SAMPLE   =   1493.0
 MINIMUM ELEVATION OF SAMPLE   =   1396.0
 AVERAGE SOIL DEPTH (M)        =    0.425
 AVERAGE SLOPE OF SAMPLE       =     15.2
 MAXIMUM SLOPE OF SAMPLE       =     22.0
 NUMBER OF ACTIVE LOCATIONS    =       75
```

Yr	Dy	Precip	Rain	Snow	Sn-cover	Snowmelt	Sublim	PET	PETRS	Evapotrs
1980	366	183.749	183.749	0.000	0.000	0.000	0.000	1040.371	825.692	183.471
1981	365	117.239	117.239	0.000	0.000	0.000	0.000	1049.372	832.835	117.181
1982	365	190.513	190.513	0.000	0.000	0.000	0.000	1031.790	818.881	182.535
1983	365	331.425	331.425	0.000	0.000	0.000	0.000	1024.139	812.809	298.026
1984	366	246.878	246.878	0.000	0.000	0.000	0.000	1034.486	821.020	210.995

Del-soil	Net-inf	Runoff	Out-flow	Mass-balance
0.264	0.015	0.000	0.000	0.209692837E-10
0.058	0.000	0.000	0.000	0.239158189E-10
7.978	0.000	0.000	0.000	-0.525243466E-10
32.361	1.038	0.000	0.000	0.617736307E-10
35.700	0.183	0.000	0.000	-0.295433521E-10

(Output file "v23" continued)

```
Global Summary Statistics (mm/year):
 ------------------------------------------------

 Precipitation..................        204.118706
 Rain...........................        204.118706
 Snowfall.......................          0.000000
 Snow-cover.....................          0.000000
 Snow-melt......................          0.000000
 Sublimation....................          0.000000
 Potential Evapotranspiration....      1047.419091
 Actual Evapotranspiration.......       190.888686
 Change in Soil Moisture.........         0.848292
 Net Infiltration................         8.587232
 Runoff Generation...............         5.171421
 Cumulative Daily Run-on.........        20.074500
 Outflow.........................         3.794496
 Average Mass Balance Error......     0.267996E-13
 Average Max Daily Error (mm/dy).     0.122080E-13
```

Output file "v.24" : Average Annual Map Output file: Average annual map out file consists of the average annual rates of all components of the water balance for all model grid nodes. (see Requirements Document, SDN 10307-RD-2.0-00):
file: FLXFILE (total daily fluxes)

easting	northing	precip	rain	snow-fall	snow-cover	snow-melt	sublimation	evapotrans	run-infil
del-soil	net-infil	runoff							
547601.0	4077633.0	209.40329	209.40329	0.00000	0.00000	0.00000	0.00000	189.33890	0.00000
0.76551	18.34766	0.95122							
547601.0	4077603.0	209.40329	209.40329	0.00000	0.00000	0.00000	0.00000	188.92460	0.00000
0.74201	18.61613	1.12055							
547601.0	4077573.0	209.40329	209.40329	0.00000	0.00000	0.00000	0.00000	190.84591	0.00000
0.69638	17.86100	0.00000							
547601.0	4077543.0	209.26810	209.26810	0.00000	0.00000	0.00000	0.00000	191.67847	0.00000
0.67716	16.91247	0.00000							
547631.0	4077693.0	208.72822	208.72822	0.00000	0.00000	0.00000	0.00000	190.52963	0.00000
0.68640	17.51218	0.00000							
547631.0	4077663.0	208.72822	208.72822	0.00000	0.00000	0.00000	0.00000	191.27580	0.00000
0.66965	16.78277	0.00000							
547631.0	4077633.0	208.72822	208.72822	0.00000	0.00000	0.00000	0.00000	190.75098	0.00000
0.68444	17.29280	0.00000							
run-on	mass-balance	max-balance	mass-balance #2						

0.000000	0.5673240E-13	0.3730349E-13	0.000000
0.000000	-0.1332268E-13	0.3375078E-13	0.000000
0.000000	0.1421085E-13	0.3375078E-13	0.000000
0.000000	-0.1776357E-13	0.4529710E-13	0.000000
0.000000	0.6039613E-13	0.4884981E-13	0.000000
0.000000	0.3197442E-13	0.3352874E-13	0.000000
0.000000	0.6220059E-13	0.6039613E-13	0.000000

<u>Output file "v.25"</u> : Test 0a, "Annual mass balance terms" file (see Requirements Document ,SDN 10307-RD-2.0-00):
file: annual mass balance terms

day	year	mo	ppt (mm/yr)	temp (C)	petday (pot-evaptrs) (mm/yr)	petrsday (evapo-trans) (mm/yr)	tetday (total et) (mm/yr)
1	1980	1	0.0000000	6.629	1.0204800	0.8099048	0.1231616
2	1980	2	0.0000000	6.580	1.0297500	0.8172619	0.1186508
3	1980	3	0.0000000	6.535	1.0331997	0.8199998	0.1135098
4	1980	4	0.0000000	6.493	1.0373832	0.8233200	0.1085862
5	1980	5	0.0000000	6.454	1.0419953	0.8269804	0.1038529
6	1980	6	0.0000000	6.419	1.0466564	0.8306797	0.0992792
7	1980	7	0.0000000	6.387	1.0543473	0.8367836	0.0951519
8	1980	8	0.0000000	6.358	1.0604196	0.8416028	0.0910088

<u>Output file "v.26"</u> : The *.v26 file is an echo of the geospatial input, with some additional model parameters for the separate root-zone layers that are calculated internally by the program. The file gets created before the model starts to run through the daily time series, and so this is not an output of model results, only a verification of model inputs (see Requirements Document ,SDN 10307-RD-2.0-00)

file: new debug file

easting	northing cdepth4 soiltype	(identifier)	ia (ia)	(ia)	row (row(ia), col(ia))	col.	elev.	sl(ia)	depth(ia) (1,ia)	(2,ia)	cdepth (3,ia)	cdepth cdepth (4,ia)
547601.0	4077633.0	5	341	99	1493.0	5.0	0.400	0.300	0.100	0.000	1.800	10
547601.0	4077603.0	7	342	99	1493.0	5.0	0.400	0.300	0.100	0.000	1.800	5
547601.0	4077573.0	8	343	99	1493.0	8.0	0.460	0.300	0.160	0.000	1.770	5

skmm (ia)	soilresid (soiltype(ia))	fieldcap (soiltype(ia))	soilporo (soiltype(ia))	scapmm1	scapmm2	scapmm3	rkmm	scapmmt
48.263	0.0280	0.1890	0.3220	88.2000	29.4000	0.0000	36.0000	153.6000
567.302	0.0350	0.2000	0.3300	88.5000	29.5000	0.0000	36.0000	154.0000
567.302	0.0350	0.2000	0.3300	88.5000	47.2000	0.0000	35.4000	171.1000

rocktype	imbibe (rocktype(ia))	imb2
314	3.3400000	1219.9350
314	3.3400000	1219.9350
314	3.3400000	1219.9350

2: Test Case 0A.4 (2):

From the Analysis Model Report, USGS (2001): (Section 6.1.1)
The depth of the root zone can be estimated from field studies but cannot be defined precisely. In addition, the depth of the root zone depends on variable climate and surface conditions controlling vegetation and other factors affecting evapotranspiration and is thus transient and spatially variable. Infiltration is the movement of water across the air/soil or air/bedrock interface, and percolation is defined as the downward movement of water within the unsaturated zone.

The root zone was subdivided into layers based on the estimated maximum depth of bare-soil evaporation and an estimated variation in root density. In general, the layering represents a decrease in root density with increased depth in the root zone, particularly at locations with thick soils (greater than 6 meters).]

The process is repeated for each soil and bedrock layer in the root zone (in the case of the model used in this analysis/modeling activity, a maximum of three soil layers and one bedrock layer were used) until the bottom layer is reached, which completes the forward cascade.

For thick soils, there is no bedrock layer in the root zone. The thickness of the bedrock root-zone layer is set to zero, the effective fracture porosity for the bottom bedrock layer becomes zero, and all water exceeding the field capacity of the bottom soil layer (the third soil layer) is potential net infiltration unless limited by the saturated bulk hydraulic conductivity of the underlying soil or bedrock. For locations where the soil depth is estimated to be 6 meters or greater, the underlying bedrock properties are defined using alluvium/colluvium properties.

The above description describes the process for defining the root zone through implementation of INFILV2.0, and the review of the model control file provided in this attachment (see example) verifies the thickness of the root zone is defined as required by test case 0A.4 (2). The reviewer may also review the Infilv2.for program and perform a word search on key words such as "cdepth" and "root zone".

3. Test 0A.4 (4)
From Infilv2.for
calculate storage capacities for output

```
            scapmm1 = (soilporo(soiltype(ia))
     1           -soilresid(soiltype(ia)))*cdepth(1,ia)*1000.
```

4 . Test 0A.6 (2)
Results for Test 0d Mapadd20.exe
H:\DATA\SOFTWARE\INFILTRATION MODEL\Life Cycle Docs for Infil V2\INFIL VTP and VTR\TEST 0 sequence\Test 0d>MAPADD20

1	1	1	803	803
2	1	804	422	1225
3	1	1226	349	1574

1000 63.53240
(continued)

4). continued.

Total number of cells: 1574

Parameter	Average	Maximum	Minimum
Precipitation (mm/yr):	517.305374	548.880400	494.085810
Rain (mm/yr):	449.347682	456.058310	440.368130
Snow-fall (mm/yr):	67.957692	93.753980	46.453300
Snow cover (mm/yr):	1251.088039	2630.685570	377.092720
Snow-melt (mm/yr):	55.725613	75.409700	39.558410
Sublimation (mm/yr):	5.622712	8.891950	3.283830
Evapotranspiration (mm/yr):	477.000354	708.006040	312.752110
Run-on infiltration (mm/yr):	29.383091	1561.109370	0.000000
Stored water change (mm/yr):	4.688116	192.659760	-28.843570
Net infiltration (mm/yr):	20.246651	1378.709950	0.000000
Run-off (mm/yr):	32.521266	186.960380	0.000000
Run-on (mm/yr):	388.644090	12911.750000	0.000000
Mass balance error (mm/yr):	-0.112473E-12	0.161506E-10	-0.174580E-10
Max daily error (mm/dy):	0.108147E-14	0.724754E-12	-0.767830E-12
Mass balance 2 (mm/yr):	-0.961536E-15	0.241585E-12	-0.241585E-12

5. Test0A.8(1 and 2). Example to verify average values for output files Test0a.v21, Test0a.v23, and Test0a.v24 are comparable. Following are partial printouts of EXCEL worksheets used to calculate averages for 1980 parameter for comparison with Test0a.v23 file and/or example of file provided in this attachment.

(A) Test0A.8(1 and 2)

Average for some parameters from test0a.v21 (file: 0Av21averages1980.xls) to compare with Test0a.v23 output file.

precip	ave. 183.749	net-infil	ave. 0.014852	pot-evaptrs	ave. 8.26E+02	mass-balance 2	ave. 0	del-soil	ave. 0.263543
0		0		0.809905		0		-0.12316	
0		0		0.817262		0		-0.11865	
0		0		0.82		0		-0.11351	
0		0		0.82332		0		-0.10859	

(B) Test0A.8(2)

test0a.v24 file: Statistics calculated from worksheet. (file 0A.v24, global ave.xls) to compare with test0a.v23 output file.

precip	ave. 204.1187	subli-mation	ave. 0	evapotrans-piration	ave. 190.8887	net-infil	ave. 8.587231
209.4033		0		189.3389		18.34766	
209.4033		0		188.9246		18.61613	
209.4033		0		190.8459		17.861	
209.2681		0		191.6785		16.91247	

runoff	ave. 5.171421	run-on	ave. 20.0745	mass-balance	ave. 2.68E-14
0.95122		0		5.67E-14	
1.12055		0		-1.33E-14	
0		0		1.42E-14	
0		0		-1.78E-14	

6. Test0A12(1). Partial EXCEL spreadsheet

From 0a.v22 for day 5549

net-infil	average	run-off	average	pptloc	average
3.3366	1.303965	3.9404	22.57171	34.6944	33.81884
3.3367		5.3632		34.6944	
3.3367		0		34.6944	
3.3366		0		34.672	

From 0a.v21 for day 5549

						ppt	rain	sn	sn	sn
5549	1995	-9	-9	70	11	33.81884	33.81884	0	0	0

(continue columns for 0a.v21 printout)

sub	pot evap	evapotra	run-on	delsoil	net infil	runoff	runon	fract
0	0.295857	0.322948	4.216464	13.83668	1.303961	22.57172	22.3934	0

(continue columns for 0a.v21 printout)

it	dis1	fid2	mb	mb2
3 0	.617914952	0.617915	-1.07E-14	0

7. Test0B.2 (1).

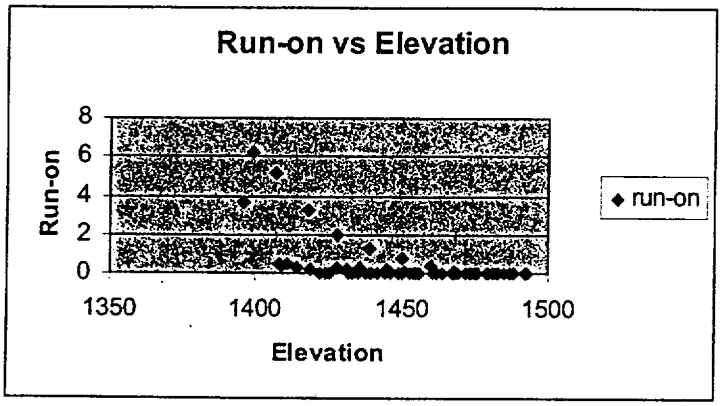
Test0b file 4ja (mod3-ppt.dat (see User Manual))

	Month	Day	Year	Day	Ppt.
Day #30	1	30	1	30	0
Day #52	2	21	1	52	0
Day #12018	11	26	33	330	0
Day #36524	12	30	100	365	0

Test0b.v21

Day	year	mo	dy	day	temp	precip
30	1	1	30	30	6.6	0
52	1	2	21	52	8.5	0
12018	33	11	26	330	10.6	0
36524	100	12	30	365	6.7	0

8. Test0B.5



9. Test0C.11: Compare .v21 and .v22 files: Partial EXCEL worksheet to verify average parameter values for day 41 (from file Test0c.v22, to compare with Test0c.v21 (day 406).

test0c.v22

pptloc	ave.	infilmm	ave.	run-off	ave.
0	0	3.141	1.173952	0	4.381269
0		3.1513		0	
0		3.1493		0	

test0c.v21

day	year	mo	day	day	temp	**precip**	rain
406	1952	2	10	41	3.9	0	0

snow-fall	snow-cover	snow-melt	subli-mation.	pot-evaptrsns	evapotrans	run-infil	del-soil
0	43.20682	6.903746	0.405041	1.0715383	0.70282727	0.248777	0.894476

net-infil	runoff	run-on	fract-inf	it	discharge-#1	discharge-#2	mass-balance	mass-balance 2
1.173953	4.381268	4.254968	0	3 0	.117409986	0.11741	-5.33E-15	0

10) Example for Test0D.6

Test0d.dat file

	easting	northing	precip	rain	snow-fall	snow-covER	snow-melt	sublimation
Line 1	545351	4077993	548.8804	455.1264	93.75398	2630.686	75.06675	8.81757
Line 805	545681	4076553	537.2708	454.7223	82.5485	2058.02	65.70224	7.67204
Line 1227	545621	4075203	502.316	446.9533	55.36266	602.1004	46.11002	4.20585

Test0d.v24 files

	easting	northing	precip	rain	snow-fall	snow-cover	snow-melt	sublimation
0d1.v24, line 2	545351	4077993	548.8804	455.1264	93.75398	2630.686	75.06675	8.81757
0d2.v24, line 2	545681	4076583	537.6208	455.0185	82.60227	2066.477	65.59	7.82131
0d3.v24, line 2	545621	4075233	502.4684	447.0889	55.37945	608.1532	46.28493	3.99887

11. Test 1D.7: Data and example calculations to validate criteria are met.

Test1D.7 fieldcap	cd1	cd2	cd3	cd4	infilmm	water1	water2	water3	water4
						(field capacity x cdepth)			
0.2	0.1	0.1	0.25	0.05	0	0.02	0.02	0.05	0.01
0.2	0.1	0.1	0.25	0.05	0	0.02	0.02	0.05	0.01
0.2	0.1	0.1	0.25	0.05	0	0.02	0.02	0.05	0.01
0.2	0.1	0.1	0.25	0.05	0	0.02	0.02	0.05	0.01
0.2	0.1	0.1	0.23	0.07	0.06	0.02	0.02	0.046	0.014
0.2	0.1	0.1	0.25	0.05	0.06	0.02	0.02	0.05	0.01

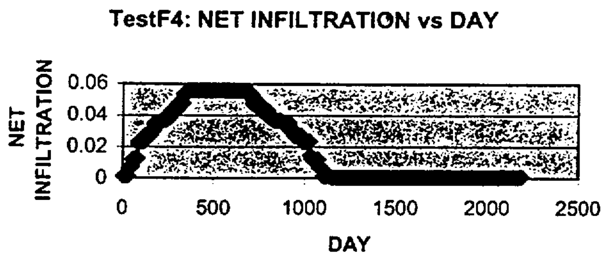
soilmm(1)	soilmm(2)	soilmm(3)	soilporo	full sat. water content (soilporo x cdepth)			
				1	2	3	4
20	20	50	0.33				
20	20	50	0.33				
20	20	50	0.33				
20	20	50	0.33				
31.74	33	75.9	0.33	0.03	0.03	0.0759	0.0231
31.74	33	82.5	0.33	0.03	0.03	0.0825	0.0165

12. Test1F.3: Partial data and calculated average.

1f net infil	ave.	1e net infil	ave.
	7.179947		9.131072
0.09652		9.42118	
7.00786		9.22123	
9.30733		10.52093	
10.07382		10.95417	
10.07382		10.95417	

13) Test 1F.4

(1) and (3): Plot for validation (See next page.)



(2): Convert ks (kg sec /m^3) to mm/day

From Infilv.for file:

c use 86400*9.8 for kgm/sec^2 to mm/day conversion

c mult. by user specified scaler sksfact (1000)

skmm = soilks(soiltype(ia))* 86400. * 9.8 * sksfact

= 0.048mm/day

From test1f.v21, max net infiltration = 0.055

14. Test1F.10

From Requirements Document, 10307-RD-2.0-00:

$$Prs - SF + SM + IR - CRZWC - ET - NI - O = 0 \quad (1)$$

where *Prs* is precipitation (rain or snow), *SF* is snowfall, *SM* is snowmelt, *IR* is infiltrated surface water run-on, *CRZWC* is the change in root zone water content, *ET* is evapotranspiration, *NI* is net infiltration, and *O* is surface water outflow. The parameters included in equation 1 are developed through the software program functional requirements

$$\boldsymbol{Pr + SF - CSP - S + IR - CRZWC - ET - NI - O = 0} \quad (2)$$

where *Pr* is precipitation as rain only and *CSP* is the change in snow pack depth and S is sublimation.

TEST	easting	northing	precip	rain	snow-fall	snow-cover	snow-melt	subli-mation	evapo-trans
2B.7	547601	4077633	0	0	0	0	0	0	18.96155

	run-infil	del-soil	net-infil	runoff
2B.7	0	-35.4585	7.31946	9.17748

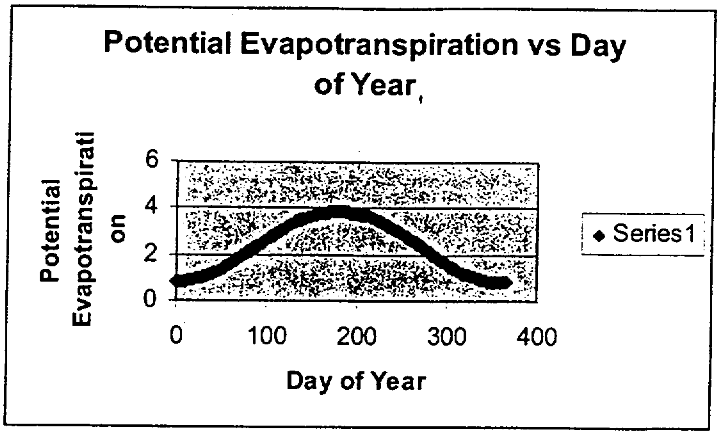
PRS-SF + SM + IR - CRZWC - ET - NI - O = 0

Example: Test 2B.7 (.v24 file):

0 - 0 + 0 + 0 - -35.4585 - 18.9615 - 7.3.1946 - 9.17748 = 0

The values for variables in Equation (2) verify the sum is equal to zero.

15. Test 2A.2



16. Test2C.4: ET average

test2c.v24	test2b.v24
23.03395	23.598268

17. Test2D2

test2d.v21	ave. netinfil	test2c.v21	ave. netinfil
net-infil	0.649936	net-infil	0.649835
1.299871		1.299671	
1.29979		1.299495	
1.299665		1.299326	
1.299534		1.299143	

18. Coefficient of Variation for Potential Evapotranspiration

test2d.1	
Std. Dev.	45.38071
Average:	310.8778
Coeff.Var.	0.146

test2c.1	
Std. Dev.	17.81358
Average:	649.9275
Coeff. Var.	0.0274

Test2a.1	
Std. Dev.:	13.2533
Average:	1098.674
Coeff. Var.:	0.0121

Test2e.1	
Std. Dev.	9.064882
Average:	944.9564
Coeff.Var.	0.0096

Test2b.1	
Std. Dev.	48.3839
Average:	1038.631
Coeff. Var.	0.0466

19.

Test2E.1		Test2E.2	
Ave annual pot et		Ave net infiltration	
test2c.v21	1.410699	test2c.v21	0.011242
test2e.v21	2.049086	test2e.v21	0.007903

20. Test2F.2: Parameter conditions set for test. Refer to the model control file and Validation Test Plan, Document 10307-VTP-2.0-00..

Type	rkcp	et	residpor	beta	alpha	ksat	PE	B	n
500	0.01	0.01	0.10	-1.5	1.00	1.3E-07	-154.6	5.02	1.56

vg-alpha	fracks	imbibe	potir
1560	2.9E-07	1.00	0100

(From 10307-VTP-2.0-00. Refer to Test2f: Test Description, (pp45-46) and Table A1.)

21 Test2G.2;Test2H.2

Test Day 1	Total ET	Total Net Infiltration
test2f	186.6368	48.74017
test2g	203.3789	0
test2h	191.1888	13.09356
test 2I	151.4694	50.84372
test2j	181.6509	51.31624
test2k	303.8083	7.877083

22. Test 3C.3: From Infilv2.for:

```
set infiltration capacity using soil ks
c       and estimated storm duration
c       winter storm = 12 hours, summer storms = 2 hours
        if((dn(j).gt.183).and.(dn(j).lt.274)) then
                skmmp  = skmm/12.
                imbp   = imb/12.
        else
                skmmp  = skmm/2.
                imbp   = imb/2.
```

23. Test 3G.1

TEST	TOTAL RUN-OFF	MAX RUN-OFF	AVE ET
3F	3754.357	1.8111	4.632668
3G			4.769688

APPENDIX 3 FIGURES

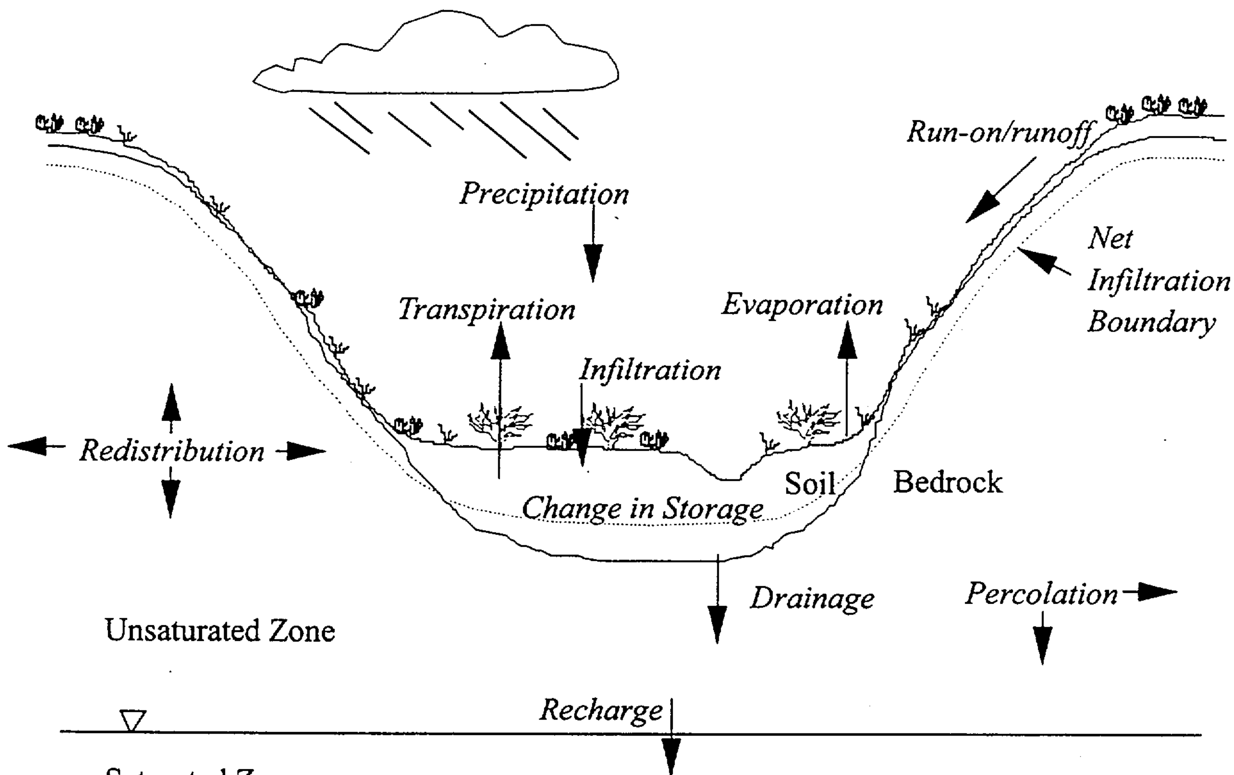
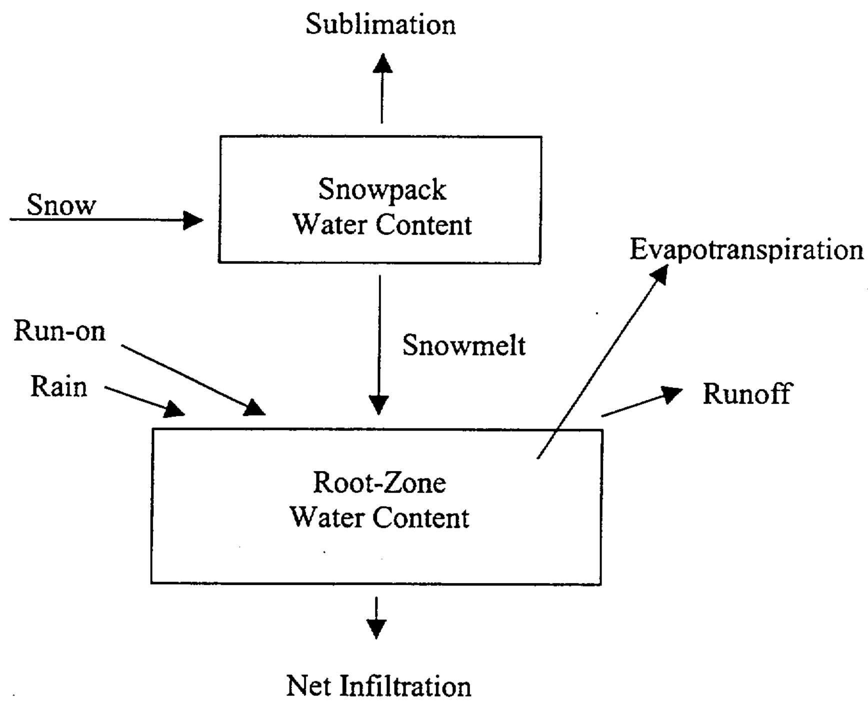


Figure 3-1. Field-scale water balance and processes controlling net infiltration (from Flint et al., 1996, Figure 3).



Change in Root-Zone Water Content:

If water content < water content at field capacity,

change in water content = Rain + Run-on + Snowmelt - Evapotranspiration

If water content < porosity > water content at field capacity,

Figure 5-1. The daily root-zone water-balance used to model net infiltration.

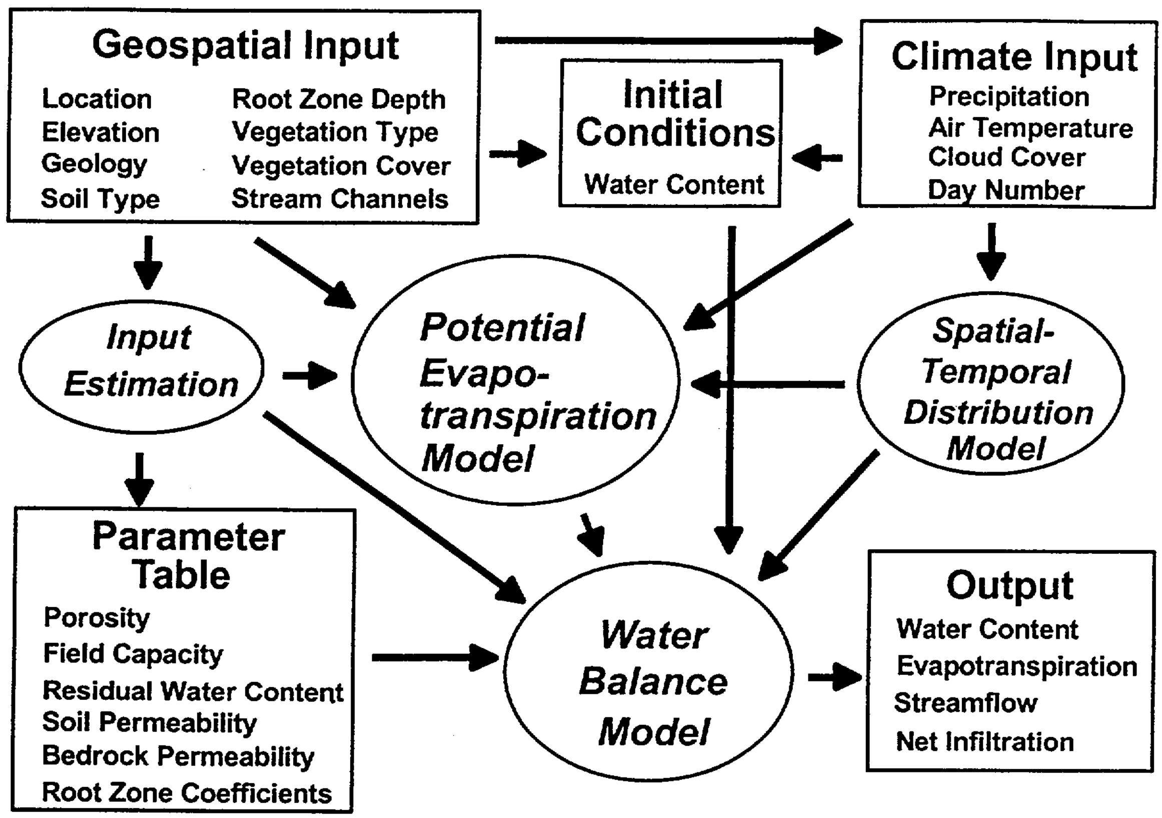


Figure 6-1. Major components of the net-infiltration modeling process.

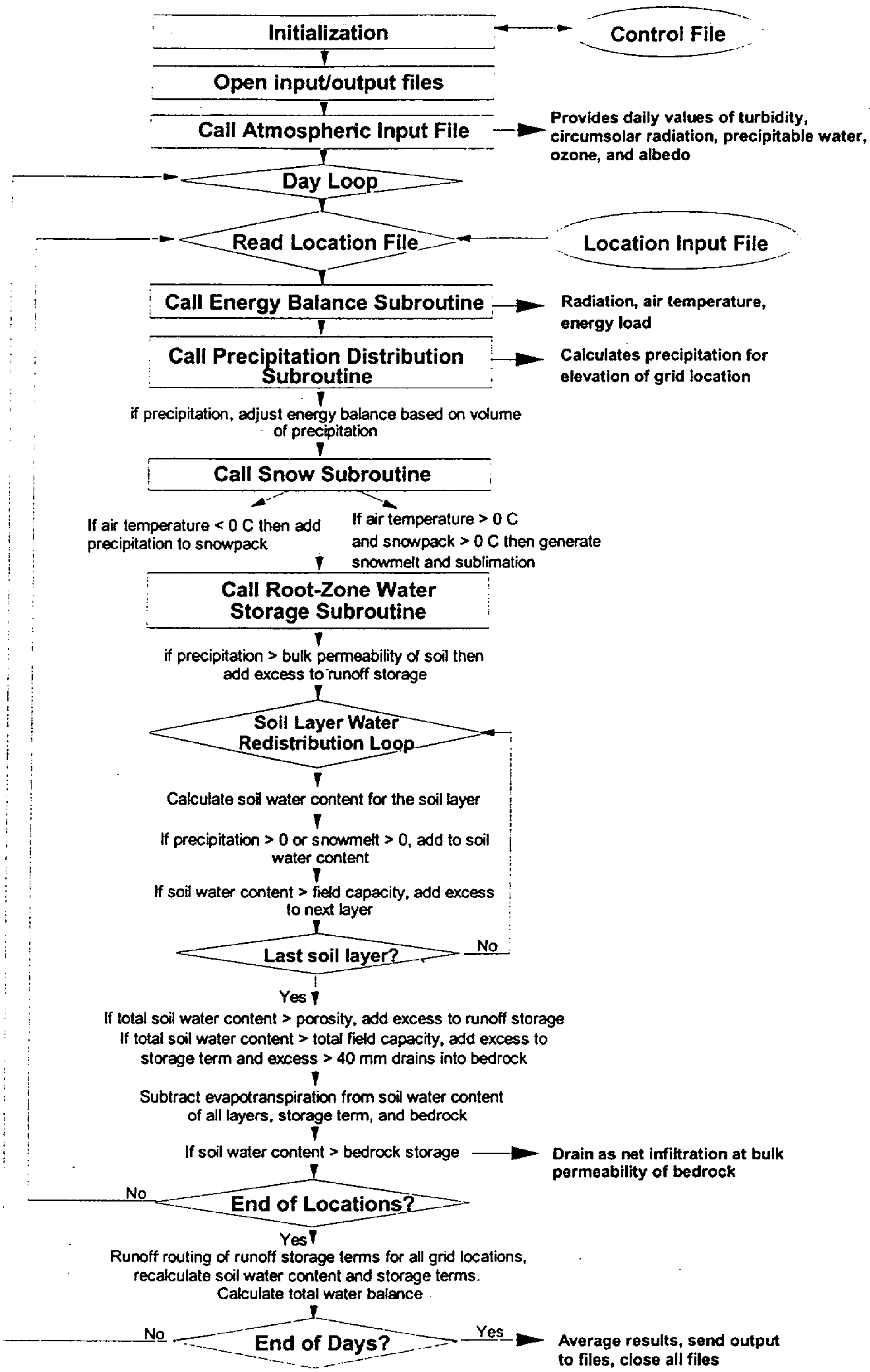


Figure 6-2. Flow chart of the model algorithm used for simulating net infiltration.

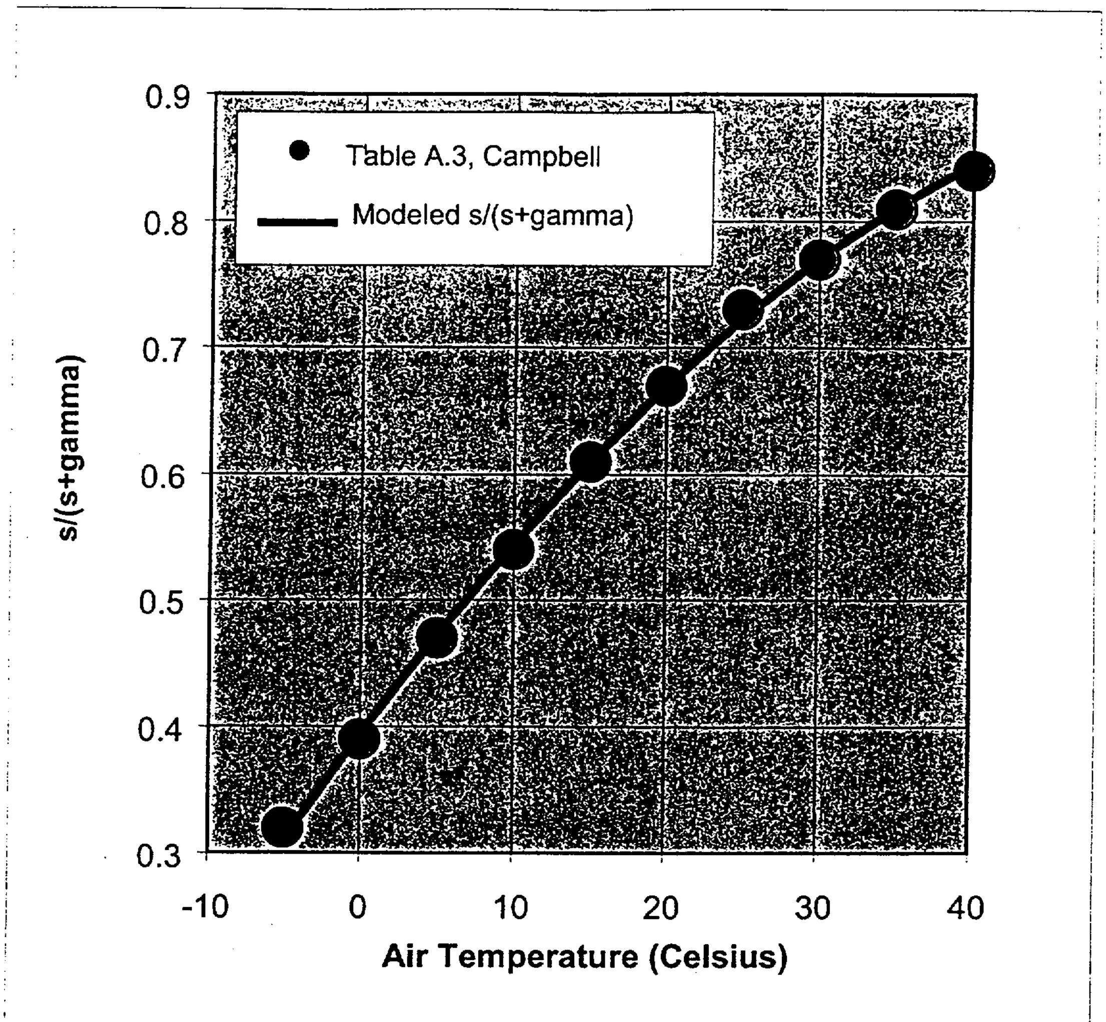


Figure 6-3. Relative effect of air temperature change on the modeled s/(s+γ) term of the Priestley-Taylor equation used for estimating potential evapotranspiration. (DTN: GS000300001221.009)

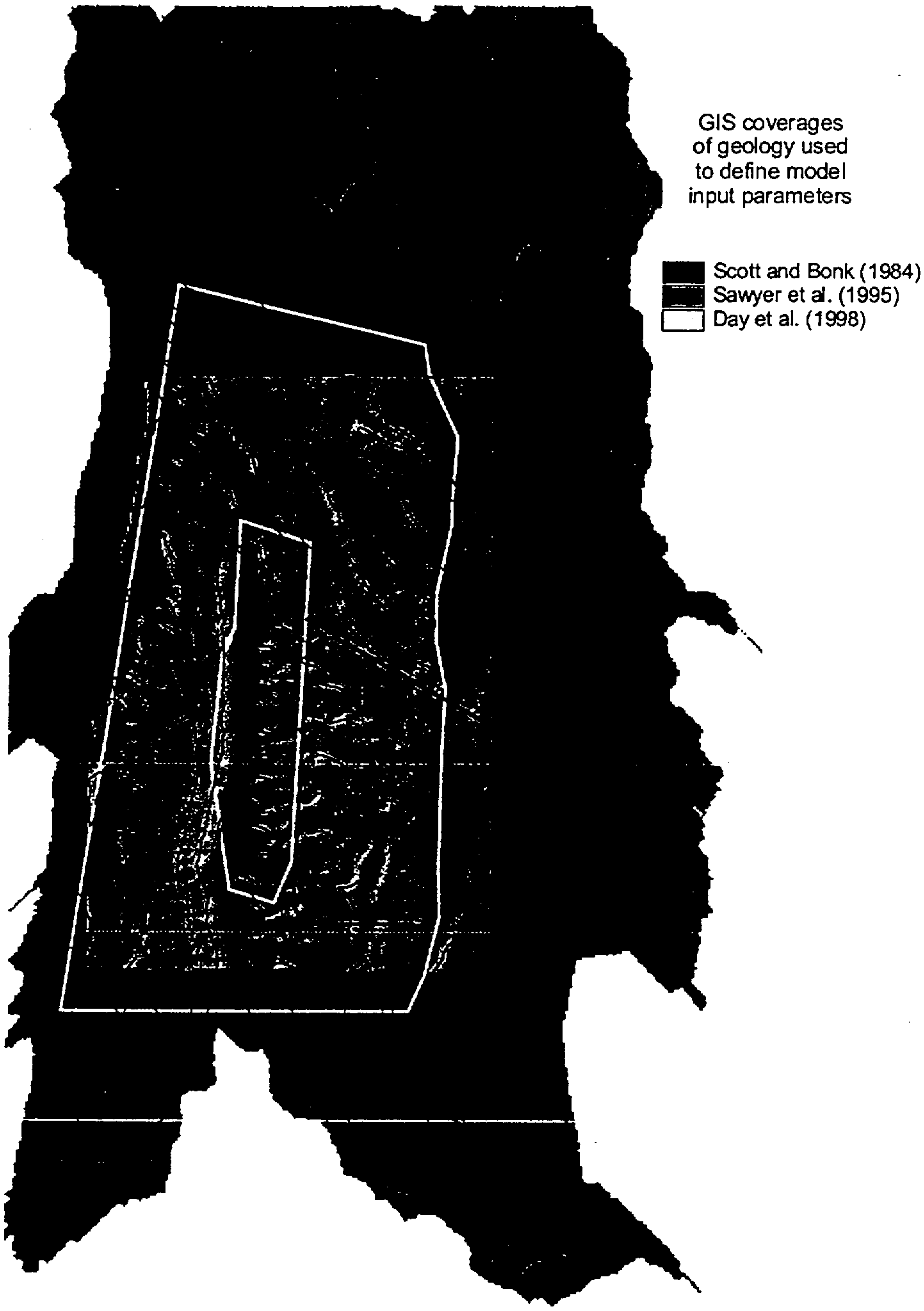


Figure 7-1. Overlay of the three geologic maps used to define rock types underlying the root zone and included in the bottom root-zone layer (Day et al., 1998, DTN: GS971208314221.003; Scott and Bonk, 1984, DTN: MO0003COV00095.000; Sawyer et al., 1995, DTN: GS000300001221.010)

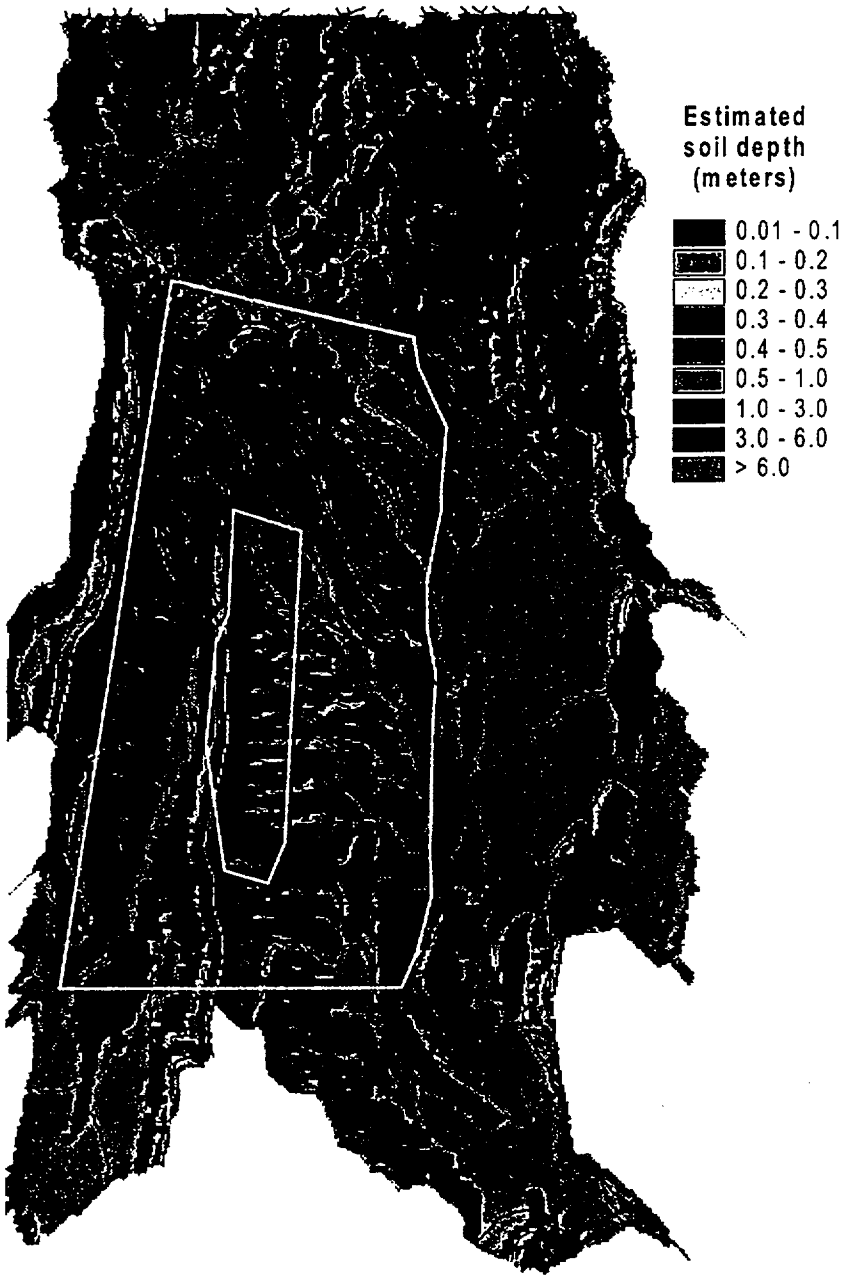


Figure 7-2. Estimated soil depth (DTN: GS960508312212.007) using the 1996 soil-depth class map and calculated land-surface slope (DTN: GS000308311221.004).

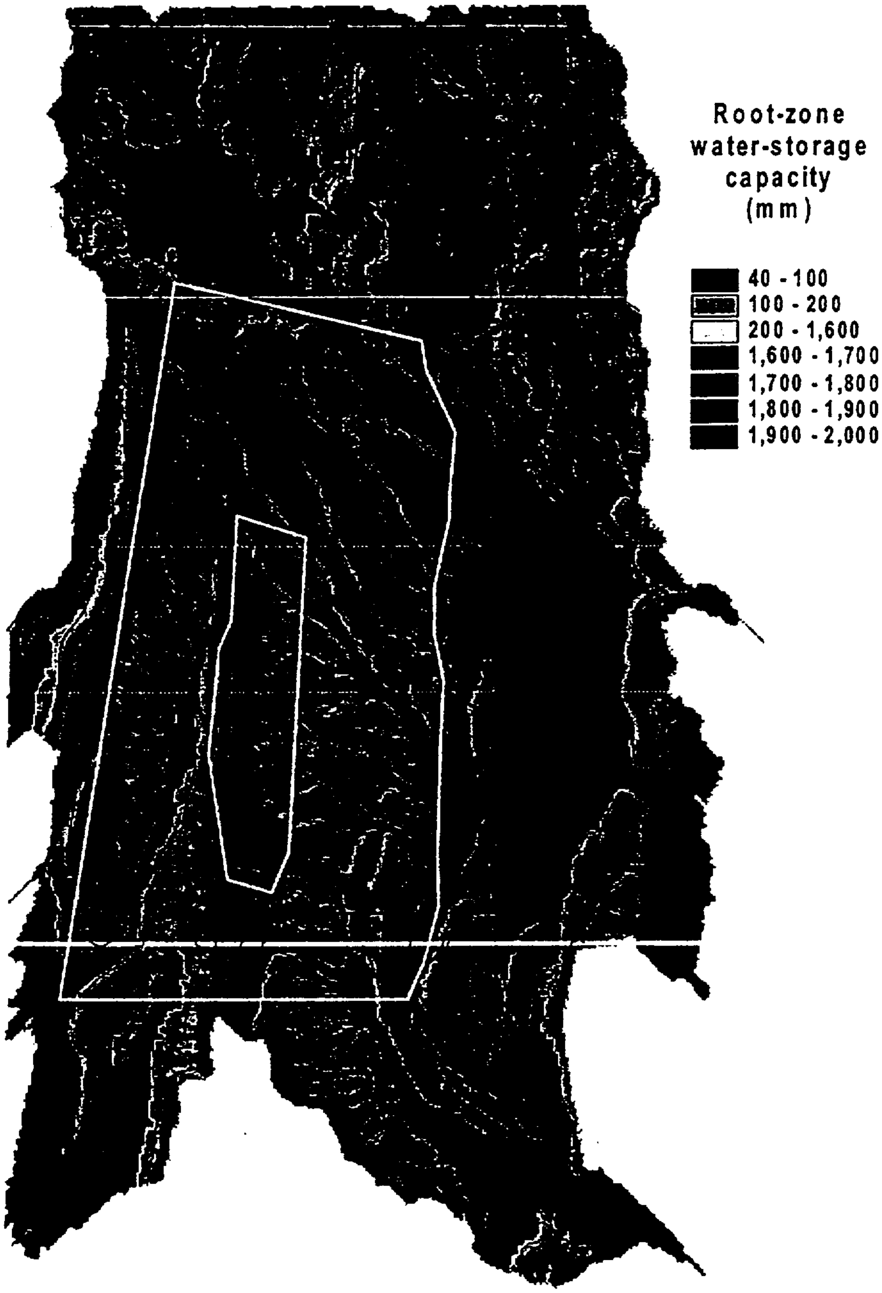


Figure 7-3. Total water-storage capacity of the modeled root zone, including bedrock and soil layers (DTN: GS000308311221.004).

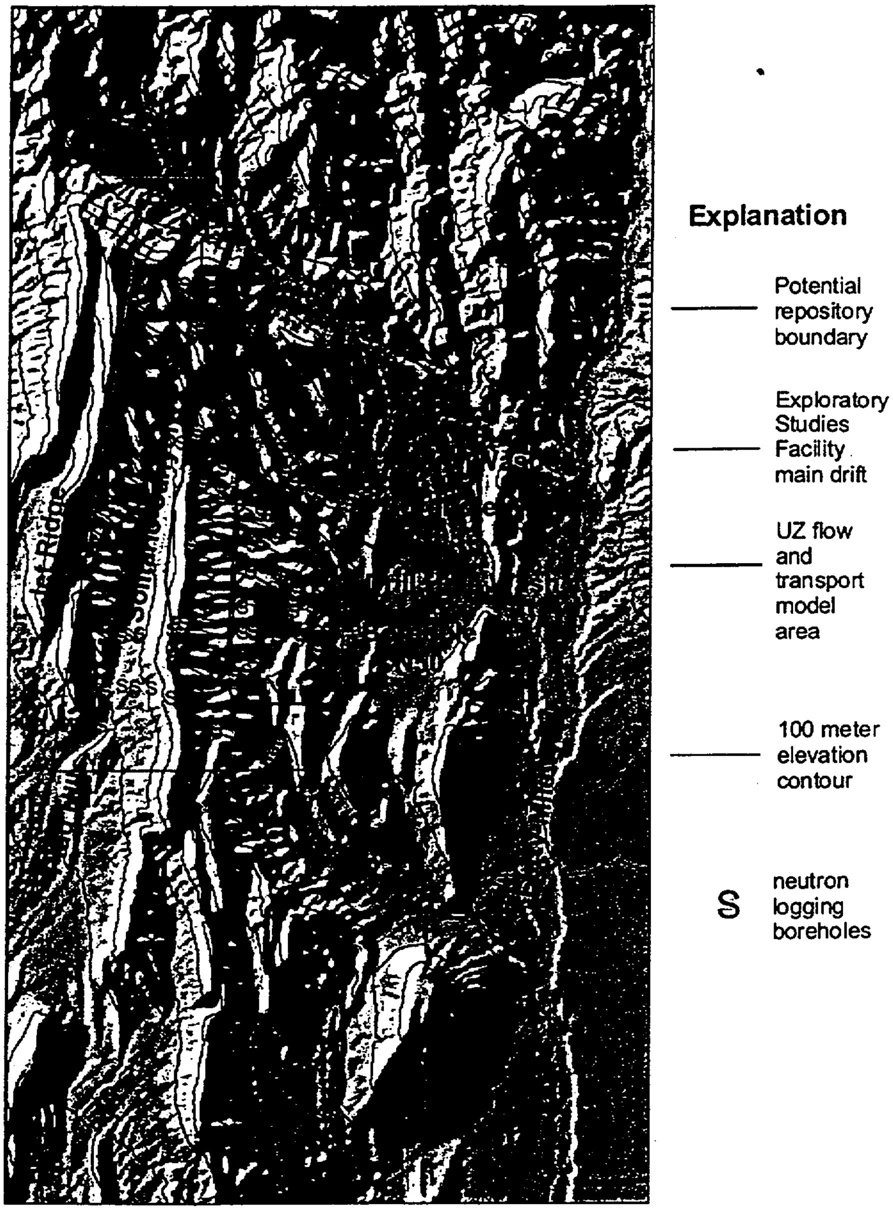


Figure A1-1. Yucca Mountain DEM used to define the geospatial-input parameters and watershed modeling domains (DTN: GS000308311221.006).

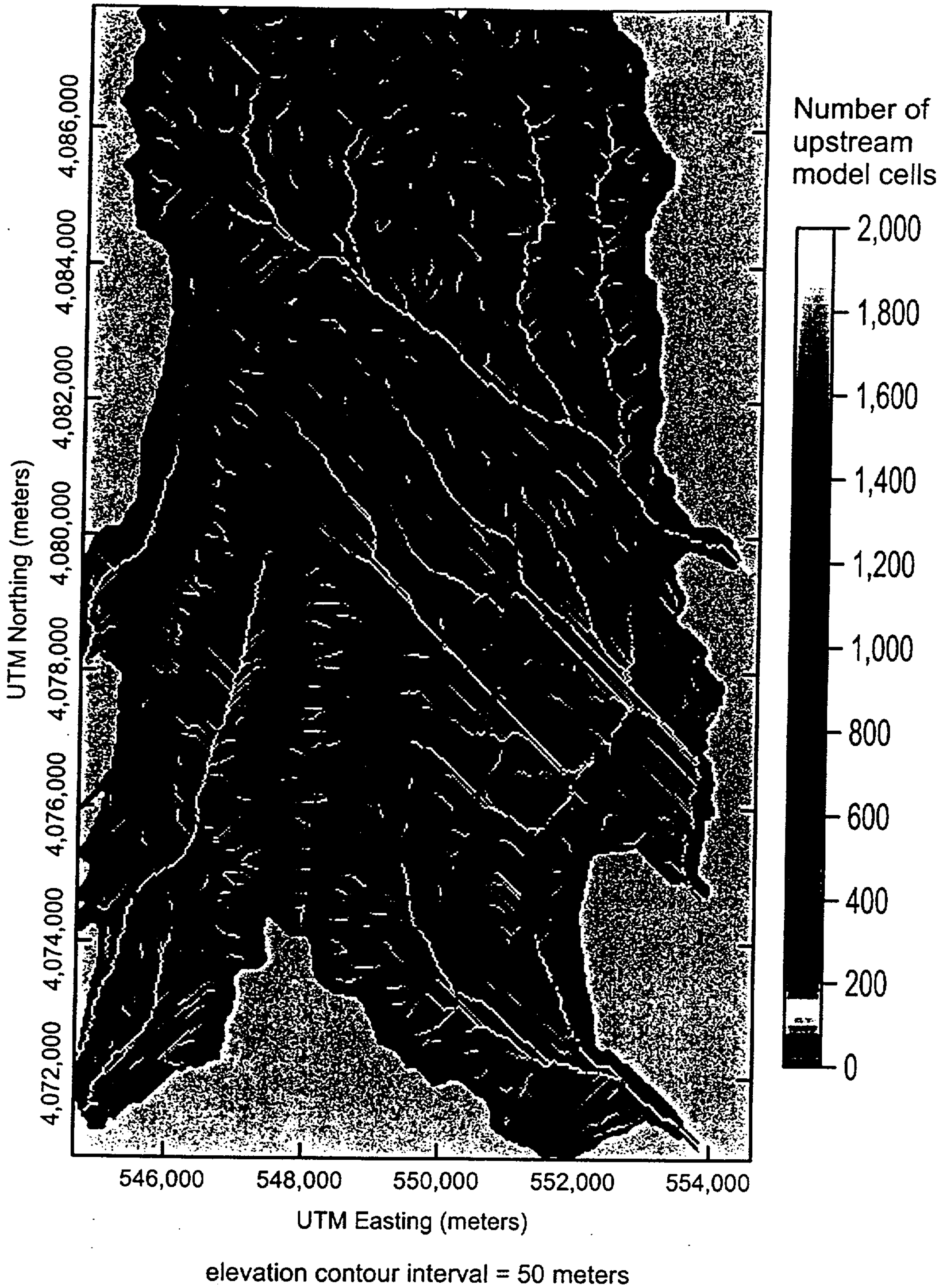


Figure A1-2. Isolation of the drainage networks overlying the area of the UZ flow and transport model.